The George W. Woodruff
School of Mechanical Engineering

(NASA-CR-182986) PERSONNEL TRANSFER AIRLOCK (Georgia Inst. of Tech.) 167 p

N90-71227

Unclas
00/37 0279977

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THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

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MECHANICAL DESIGN ENGINEERING

NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

PERSONNEL TRANSFER AIRLOCK

JUNE 1987

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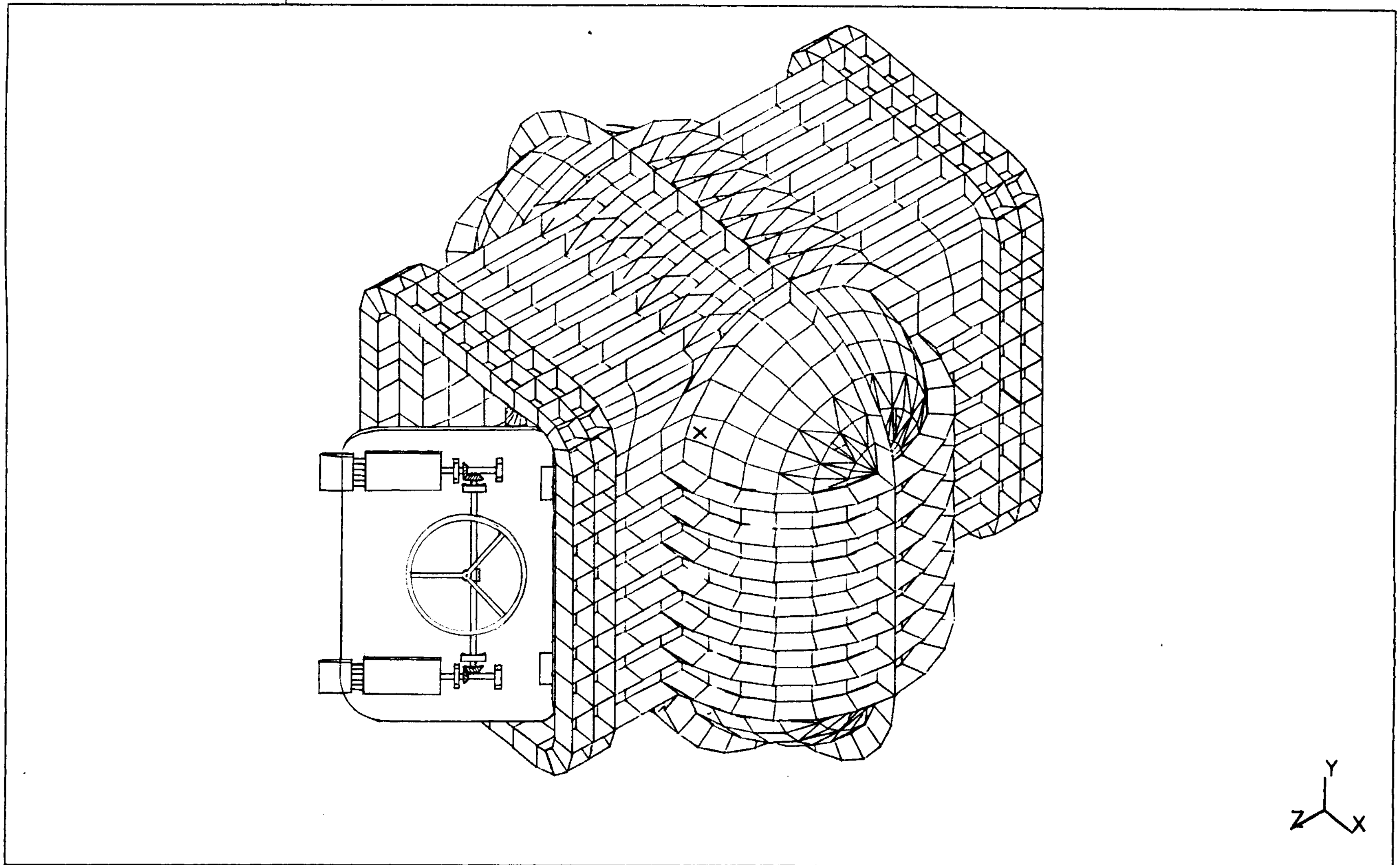
SDRC I-DEAS 3.8. Pre/Post Processing 24-MAY-87 20:21:18
DATABASE: REINFORCED AIRLOCK UNITS = IN
VIEW: ISO DISPLAY: No stored OPTION
Task: Model Preparation



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ABSTRACT

The purpose of this report is to provide a description of the design of an airlock for use on the lunar surface. The design provides an efficient means by which to transfer two astronauts per evacuation/pressurization cycle from the lunar base module to the lunar surface and back with minimal loss of or contamination of module atmosphere. The design incorporates the airlock module itself along with separate hatch modules for connecting the airlock to the base module and providing the access to the lunar surface. In this way, the hatch modules can be used elsewhere in the lunar base construction. The design further contains an evacuation system to pump base module air into and out of the airlock and a cleaning system to remove particulate matter from the astronauts' spacesuits to prevent contamination of the base module atmosphere.

Additionally, the report contains an analysis of the finite element procedure used in designing the airlock and hatch modules, along with analyses of the vacuum system, hatch door seal, locking mechanism, cleaning system, and projected costs involved in this design. Recommended areas for further study are also summarized.

PROBLEM STATEMENT

BACKGROUND

Proposed design of a permanent manned lunar base revolves around the concept of modular working and living facilities. Since the lunar atmosphere is essentially a vacuum, some means of transfer between the pressurized module environment and the lunar surface is required. Airlocks, such as that between the space shuttle cargo bay and the working quarters, are commonly used to accomplish this transfer. However, the lunar environment introduces conditions which make it inappropriate to use existing designs in their current form. Most importantly, dust particles from the lunar surface brought into the airlock by the astronauts must be removed prior to entering the module.

OBJECTIVES

1. Provide a means of transferring personnel and small items from the module to the lunar surface and back with minimal loss of module atmosphere.

2. Remove dust particles picked up on the lunar surface from personnel before they enter the module.

3. Provide a means of verifying the absolute pressure level in the airlock.

4. Design a system for ease of assembly and operation, while providing maximum reliability and safety.

5. Design system components for maximum interchangeability and arrange for ease of access in order to facilitate maintenance.

CONSTRAINTS

1. The system must be able to withstand the lunar environment without significant degradation due to:

   A. Radiation
   B. A temperature range from -125°C to +125°C
   C. Vacuum.

2. All components must be transported within the cargo bay of the space shuttle or by a similar vehicle and then transferred to the lunar surface.

3. All passageways must be operable from either side by a single person and in the absence of power.

4. The passageways and joints in the airlock must be sealed such that they can withstand a pressure gradient of 10 psi plus safety allowances in each direction.

5. All mechanical equipment must be accessible from inside the airlock or the lunar base module.

6. The weight of the system should be minimized in order to limit transportation costs.

DESCRIPTION

INTRODUCTION

The main purpose of the personnel transfer airlock is to provide a means by which lunar base personnel can safely enter and exit the base module with minimum contamination of and loss of base module atmosphere. The design can be divided into two main components: 1) the airlock module and 2) the hatch module. A hatch module attaches the airlock module to the lunar base module. Additionally, a hatch module is attached to the opposite side of the airlock module and opens onto the lunar surface. The airlock is sized to allow two astronauts to exit or enter the lunar base for each evacuation/pressurization cycle. The airlock and hatch modules were designed as separate entities to allow the hatch to be utilized in other locations, such as between base modules or as openings to totally separate facilities. In this respect, all hatch doors would then be "standardized". Additionally, if desired an airlock module could serve other purposes, such as a small storage area.

OPERATIONAL PROCEDURE

To exit the base, the two astronauts put on their spacesuits, open the interior hatch door, and enter the airlock, which would be at lunar base atmosphere. After closing and securing the hatch door between the airlock and the base module, the astronauts evacuate the atmosphere from the airlock into the base module's air storage system. Once the atmosphere in the airlock reaches a level of one millibar, the astronauts unlock the exterior hatch door, vent the remaining air to the outside, open the exterior hatch door and exit to the lunar surface, securing the door closed behind them. To return to the base module, the astronauts first brush themselves off as completely as possible, and then open the external hatch door, enter the airlock, and secure the door closed behind them. Pressurization of the airlock with base module atmosphere is initiated. Simultaneously, the astronauts further clean the lunar dust from their spacesuits with the cleaning nozzles provided. The dust falls through the floor and is trapped in filters. The clean air is then circulated back into the airlock. Once a safe level of particulate in the air is reached and an atmosphere level of 10 psi, which is equal to that of the base module atmosphere, is reached, the astronauts open the interior hatch door and enter the base module, securing the door closed behind them. It should be noted that all devices requiring operation to enter or exit through the airlock and hatch modules are designed to be operable by one astronaut.

AIRLOCK MODULE CONSTRUCTION

The airlock module is sized to accommodate two astronauts in the main compartment and has an extension protruding from each side to provide a flange area for mating with a hatch module and to provide space for the open hatch door. (See Figures 1, 2, and 3) The airlock module is symmetric about the x-y plane and the y-z plane, but not the x-z plane. The lack of symmetry in the x-z plane allows the extension floor to remain on the same plane as the airlock floor. The airlock module skin is a high strength aluminum alloy, 5052. The airlock skin is a pressure vessel and was designed to support a change in pressure of fifteen psi. Because of the deformation induced in the skin by this pressure, the skin is reinforced with ribs. (See Figure 1) All ribs extend from the airlock skin in a radial direction away from the center of the airlock and are high strength aluminum alloy, 6063. The skin and ribs of the airlock module have an approximate weight of 1270 earth pounds and 1110 earth pounds, respectively, for a combined total weight of 2380 earth pounds. The total volume occupied by the airlock module when constructed is 725 cubic feet.

FLOOR CONSTRUCTION

Upon entering the airlock, personnel will pass through the mating extension to stand on a floor raised two feet above the bottom of the airlock. The floor, which extends into the extension areas, consists of three grate panels of high strength aluminum alloy, 6063. The panels will rest on lips around the interior circumference of the airlock and on two cross braces. The lips and cross braces are also 6063 aluminum alloy. The panels can be lifted individually to expose the cleaning equipment housed below the grate panels. Approximate weights in earth pounds for the grating and supporting braces are 230 and 45, respectively. The actual floor area within the main compartment of the airlock is 33 square feet.

CLEANING SYSTEM

The cleaning equipment consists of air hoses, ASHRAE 30% preliminary filters, a high efficiency secondary HEPA filter, a self-cleaning radial aluminum blade blower, and a motor. (See Figure 4) During the cleaning process, compressed air from the base module is ducted into the airlock via the hoses and exits at a high velocity of 44 feet per second. The astronauts use the hoses to blow the particulate matter off their spacesuits. The cleaning process is expected to take from 0.5 to 1.5 minutes. The particulate matter falls through the floor grating into the preliminary filter system. The particulate not caught in the preliminary filter is recirculated into the high efficiency secondary filter which will remove all particles of 0.0003 millimeter or larger. The recirculation of air is accomplished with the blower run by the motor. The filtered air is then ducted up through the sides of the airlock module and re-enters the airlock via vents near the ceiling. The major components of the cleaning system, the blower and the motor, weigh approximately 10 and 20 earth pounds, respectively. The two HEPA filters weigh approximately 50 earth pounds each and miscellaneous hardware, such as the hoses, ducts and preliminary filters, weigh approximately 50 earth pounds, for a total combined weight of 180 earth pounds for the cleaning equipment system. The main components of the cleaning equipment occupy a volume of 5 cubic feet below the floor grating.

EVACUATION SYSTEM

The airlock module evacuation system is contained completely within the base module and is connected to the airlock by means of hoses enclosed within a conduit which passes between the base module and the airlock module. One hose carries air from the airlock to the vacuum pump when the system is being evacuated and the other carries air from the base module to the airlock when the airlock is being pressurized. The conduit also serves to carry electrical wiring for the lighting, cleaning, and control and monitoring systems of the airlock.

The evacuation system schematic is shown in Figure 5. The system is based upon three Leybold-Heraeus model number S160C rotary vane vacuum pumps connected in parallel. Each pump is powered by a 7.5 horsepower motor. Additionally, each pump is connected in series to a model AS dust separator and a Secuvac[tm] valve upstream of the pump, with a second identical dust separator downstream of the pump. Each pump is separated from the system by a pair of ball valves, allowing the system to operate with only two pumps while a third is being serviced. Evacuation time when all 3 pumps are running is 10.54 minutes. The complete vacuum system weighs 1295 lbs, of which 900 lbs is the weight of the three pumps. The complete system occupies a volume of 12 cubic feet.

To guard against a power failure, the airlock module has a fail safe operating system which allows it to be cycled even when the vacuum system is inoperable. During an emergency or power failure, the airlock can be evacuated by means of a manually operated dump valve which exhausts the airlock atmosphere to the lunar surface. To allow passage back into the module, a similar valve between the base module and the airlock is used to vent the base module atmosphere into the airlock once the outer airlock door has been sealed. Since operating the airlock in this mode necessitates the loss of the atmosphere within the airlock, this procedure would only be used when an emergency requires immediate transfer through the airlock, without waiting for the normal evacuation procedure.

HATCH MODULE CONSTRUCTION

The hatch module is also constructed of high strength aluminum, 5052, for the skin and has an external supporting rib structure attached to the module skin and running between the two mounting flanges. (See Figure 6) The mounting flange extends radially outward from the hatch module shell. The hatch module will be bolted and statically sealed to the airlock module and/or base module. The actual door area through which the astronauts pass is surrounded by a flange. The door seals against the flange and hinges and locks are attached. It should be noted that the floor level is below the bottom of the actual door area, thereby requiring the astronauts to step over the bottom portion of the flange while eliminating any need to duck through the door area. (See Figure 3) The ribs and flanges are of 6063 aluminum alloy. The approximate weight distribution in earth pounds of the hatch module is: skin, 140; flanges, 270; and ribs, 420; for a total weight of 830 earth pounds. The hatch module occupies a volume of 52 cubic feet.

HATCH DOOR CONSTRUCTION

The hatch door is composed of two parallel skins, forming the front and back surfaces, supported by internal ribs running both the length and width of the door, with an additional rib running along the circumference. (See Figure 7) Constructed of 5052 aluminum alloy, the skin weighs approximately 330 earth pounds and the ribs, constructed of 6063 aluminum alloy, weigh approximately 240 earth pounds, for a total weight of 570 earth pounds for the hatch door. The hatch door has a volume of 7.5 cubic feet.

HATCH DOOR MOUNTING MECHANISM

The door will operate as a standard swing hinged door and will be mounted to the hatch module with two hinges. (See Figures 8 and 9) The hinges are Daro Industries series 625 or comparable, high strength tool steel, with two concealed ball thrust bearings plus two radial needle bearings which glide smoothly on a hardened and ground pin. They are designed to withstand the weight of the door and a radial load of 25,000 pounds and weigh approximately 20 earth pounds each.

HATCH DOOR LOCKING MECHANISM

The locking mechanism consists of two wedge-like inclined planes mounted upon sliding shafts at the edge of the door. These wedges translate into mating sockets, creating a sealing force of approximately 20,000 pounds. (See Figure 10) The wedges and their mating sockets are constructed of a high strength aluminum alloy, 6063, and roller bearings are embedded into the sockets to reduce sliding friction. Three tool steel rods, which are mounted into the sliding wedges slide through a set of bearings and are attached to a block at the opposite end. (See Figures 8 and 9) The block contains a bronze bushing power screw nut. This nut is powered by a power screw and shaft fixed to the door by means of two thrust bearings. A bevel gear is attached to the power screw shaft and mates with an identical bevel gear to change the rotational motion 90 degrees. This bevel gear connects to another shaft which runs vertically along the door and is held in place by two radial bearings. In the center of this shaft is a worm gear. Mating with this middle worm gear is a worm that allows the rotational motion to be turned another 90 degrees. This worm is connected to a third shaft that run through the hatch door. Connected at each end of this shaft is a wheel which the astronaut operates to open and close the door. The entire locking mechanism has a weight of approximately 200 earth pounds and occupies a volume of two cubic feet.

The mating sockets of the sliding wedges are designed to be bolted to the wall; therefore, if the locking mechanism fails the mating socket can be removed and the door opened once the pressure on each side of the door is equalized.

HATCH DOOR SEAL

A BAL face seal was chosen for the hatch door application. (See Figure 11) This seal consists of a butyl rubber outer seal with a durometer hardness of 60 to 70. A helical spring with canted coils is contained within this outer polymer sheath and maintains a relatively constant compression force upon the seal in spite of large variations in door clearance. A small electrical resistance wire is contained within the spring in order to maintain the polymer at a minimum temperature. The polymer portion of the seal has the same cross-section around the entire door circumference, while the spring within the seal varies from a smaller diameter on the hinge side of the door to a larger diameter on the opposite side. The spring tapers linearly from the smaller diameter to the higher diameter along the top and bottom of the door. Additionally, the stiffness of the smaller diameter portion of the spring is greater than that of the larger diameter portion.

MOUNTING FLANGE SEALS

Static seals are utilized for the bolted flanges to mount the hatch module to the airlock and base modules. The static seals employ o-ring design techniques and materials common to earth bound vacuum chambers. The single difference is that the seal is not truly an o-ring since it fits into a gland about a rectangular opening. However, the cross-section of the seal is still circular; thus, the assumptions of standard o-ring design remain valid.

ANALYSIS

INTRODUCTION

Certain basic assumptions were made during the design process. First, it was assumed that the airlock and hatch modules would be secured under a tent-like structure which would support two meters of lunar soil pressure to provide insulation from the radiation on the lunar surface. Secondly, the assumption was made that adequate electrical power could be obtained from the base module to run the cleaning and evacuation equipment, lights, and the heating element in the hatch door seal. Finally, it was assumed that space in the base module would be available for housing the evacuation equipment.

The main components of the personnel transfer airlock system include: geometry, structural analysis, hatch door mounting and locking mechanisms, hatch door seal, evacuation system, and cleaning system. An analysis of each of these components, as well as a cost and volume analysis, follows.

AIRLOCK GEOMETRY

Several factors influenced the determination of the best geometric shape for the airlock. These included the number of astronauts to be accommodated at one time, the placement of equipment, stress considerations, the type of construction material to be used, and evacuation time. The optimum design was chosen to accommodate two astronauts. It was assumed that the "buddy system", i.e., two astronauts per trip, would most often be utilized during an excursion to the lunar surface. A combination of spherical and cylindrical geometries was utilized in the shape of the airlock as it presented the optimum design for stress while providing an adequate amount of volume for astronaut maneuverability for a given evacuation time.

The airlock module structure is ten feet high with a length of ten feet and a width of five feet. All edges are rounded with a 2-1/2 foot radius. The extension protruding from each side is seven feet eight inches high with a length of five feet and a width of two feet. The airlock module skin has a thickness of three-eighths inch. All ribs extend six inches from the airlock skin. The ribs on the top and bottom cylinders are spaced eight inches center to center, while the side ribs are spaced ten inches center to center. One rib will lie on the circumference of the airlock in the x-y plane. The mating flanges have a width of six inches and rib and flange thickness is one-half inch. The floor grating within the airlock is one inch thick. The lips and cross braces on which the grate panels rest have widths of two inches and four inches, respectively.

A description of alternative designs considered and reasons for not selecting these designs is contained in Appendix 4-A.

HATCH MODULE GEOMETRY

The hatch module is seven feet eight inches high, five feet in length, with a width of one foot. The mounting flanges are six inches wide with a width of one-half inch. The one-half inch thick ribs are spaced eight inches center to center on the top and bottom and ten inches center to center on the sides. The door area through which the astronauts pass is six feet four inches high by three feet eight inches wide, with an eight inch wide by one-half inch thick flange surrounding it.

The hatch door is seven feet high by four feet four inches wide with a thickness of three inches and corners rounded to a six inch radius. The two parallel skins are each three-eighths inch thick. All internal ribs are one-half inch thick. The center to center distance of the vertical ribs is ten inches while that of the horizontal ribs is twelve inches.

STRUCTURAL ANALYSIS

All of the structural analysis was performed using the finite element method as applied in Structural Development Research Corporation's I-Deas software package running on the Apollo computer located in the A. French Building. By entering points, lines, and arcs, surfaces were generated which represented the physical structure of interest. On these surfaces a finite element mesh was generated consisting of nodes and elements. Boundary conditions such as loads, physical restraints, and kinematic constraints were then applied at the appropriate locations and a solution was obtained. Desired information returned included deflections, reaction forces, and principal stresses at each node. Continuous tone color plots were then generated to show displacement, reaction, and stress gradients on the deformed geometry. A legend showing the gradient magnitudes along with maxima and minima were included in the plots. A description of the preliminary analyses performed and referenced plots are contained in Appendix 1. The results of the structural analysis for the final design follows and applicable plots are referenced.

Hatch Door - Two Thin Plates with Ribs

A load of 15 psi for the module pressure was utilized in the preliminary thick plate analysis; however, further examination of the design criteria indicated that the module pressure would be lower than first thought. With a module pressure from 7 to 10 psi the load of 15 psi gave an analysis case representing a safety factor of 1.5 to 2. The door was restrained as it would be under normal loading conditions, forming a seat on the o-ring. (See Figure 12) Displacement analysis yielded a maximum deflection of 0.0594 inches occurring at the center of the door. (See Figure 13) Stress analysis data yielded a maximum of 4.72E+3 psi occurring on the surface of the hatch door to which the pressure was applied. (See Figure 14) Reaction data showed a maximum of 3.78E+3 lbf along the sealing edges. (See Figure 15)

Reverse pressure of 15 psi would be the pressure present on the hatch door in the event that the airlock contained pressure while the lunar base module was evacuated. The hatch door was restrained at eight nodes to represent two hinges and two locking mechanisms on the two vertical edges of the door. (See Figure 16) The maximum deflection of 2.25E-2 inches occurred at the center of the door. (See Figure 17) The displacement of most concern was that of the nodes around which the hatch door seal would contact. The maximum deflection along the edge of the door was 1.93E-2 inches. (See Figure 17) This displacement indicated that the door would not leak in the reverse loading case. Maximum stresses on the order of 7400 psi occurred at the center of the door. (See Figure 18) The maximum reaction forces occurred at the location of the hinges and the locking mechanisms. The solution suggested that the locking mechanism would have to support a maximum load of 5430 lbf in the reverse load case. (See Figure 19)

Airlock Module - Thin Skin with Ribs

After the initial analysis to locate maximum deflection points was performed, it was determined that ribs would be needed on the cylindrical sides and top of the airlock module. The addition of the airlock module extensions to the geometry eliminated the need for ribs on the front and back face, although ribs would be needed for the walls, floor and ceiling of the extension. The same load of 15 psi of internal pressure was applied to the reinforced structure and a displacement/stress analysis was performed. The solution yielded a maximum deflection of 0.065 inches at the center of the top surface of the airlock module. (See Figure 20) This deflection along with a maximum deflection on the bottom center of the airlock of 0.0107 inches combined to give a total deflection of 0.64% relative to the undeformed geometry. The stress analysis yielded a maximum stress of 2.38E+4 psi occurring at the intersection of the extension and the cylindrical top and bottom of the airlock. (See Figure 21) Using a factor of safety of 1.5, these stresses are at an acceptable level below the yield strength of 36,000 psi.

The conclusion derived from this analysis was that the external support of the ribs provided adequate support in order to keep total deformations below 1% of the total length of the airlock module and maximum stresses below unacceptable levels.

HATCH DOOR MOUNTING AND LOCKING MECHANISMS

The two hinges employed to mount the hatch door are placed 54 inches apart center to center. Each hinge is eight inches in height with an open width of eight inches.

For the hatch door locking mechanism, the sliding wedge is 6 inches by 4 inches by 1-1/2 inches. The roller bearings mounted in the mating socket are 1/4 inch. The three rods mounted into the wedge are each one inch in diameter and the bearings through which they slide are 7.5 inches long. The block containing the power screw nut is 4 inches by 6 inches by 9 inches, with the power screw threads 2 inches in diameter cut six inches into and back along the axis of the center rod of the sliding wedge. The bevel gears are 3.5 inches in diameter and 1/2 inch thick while the worm gears are 2 inches in diameter. The diameter of the power screw shaft is 2 inches, while the diameter of the other two shafts is 1/2 inch. The operating wheels have a radius of 16 inches.

Calculations to determine the torque required on the wheel to close the door and the resulting wheel radius are given below:

Force required at each sliding wedge normal to seal:

$$F = 8820 \text{ lbf}$$

Pressure angle of wedge: $\theta = 20.6^\circ$

Force power screw is required to move:

$$P = F(\tan\theta) = 8820(\tan 20.6^\circ) = 3315.22 \text{ lbf}$$

Assume 25 turns of power screw to advance slider 4 inches:

$$\text{Lead, } L = (4/12)(1/25) = 0.0133 \text{ ft} = .16 \text{ inch}$$

Using a power screw with ACME threads, a pressure angle of $\alpha =$

20°, and a coefficient of friction $\mu = .15$:

equivalent coefficient of friction,

$$\mu'' = \mu/(\cos\alpha) = 0.15/\cos 20^\circ = .1596$$

Using a nominal diameter of d_m = 2 inches = 0.1667 ft:

$$T_{max} = (P(d_m)(L + d_m\mu''))/(2(\pi d_m - L\mu''))$$

$$T_{max} = \frac{(3315.22(0.1667)(0.0133 + \pi(0.1667)(.16))}{2(\pi(0.1667) - (0.0133)(.16))}$$

$$T_{max} = 51.44 \text{ ft-lbf}$$

Force astronaut can exert : F_a = 20 lbf

Radius needed for hatch door wheel:

$$R = T/(2)(F_a) = 51.44/(2)(20) = 1.29 \text{ ft}$$

HATCH DOOR SEAL

The durometer hardness for the polymer sheath was chosen to be in the range between 60 and 70. Polymer materials softer than this tend to tear easily and require frequent maintenance, while harder materials do not deform sufficiently under pressure to fill the flaws in the microsurface of the surface against which they seal and thus do not seal properly. A higher durometer hardness also requires a higher compressive sealing force in order to seat the seal properly.

When the hatch is closed the two sealing surfaces apply a compressive force to the sides of the spring coils, causing them to deflect inward. Under normal operating conditions, the pressure on the door tends to force the door against the seal, thus increasing the normal force on the sealing surface and increasing the integrity of the seal. When the pressure is reversed the door tends to deflect away from the seal since the door is constrained to remain against the seal only by the hinges and the locking mechanism. The finite element analysis of the final door design loaded under reverse pressure showed that the maximum deflection of the door along its circumference was less than .050 inches. The seal must tolerate this change in its compression without a significant reduction in the normal force applied to the polymer portion of the seal.

The spring maintains the normal force against the seal above the minimum level necesssary for a proper seal because an increase in the clearance between sealing surfaces is taken up by an expansion of the spring, as long as the spring does not expand beyond the point where the elastic force it supplies fails below the minimum necessary sealing force.

Data obtained from Reference 8 indicate that compression of the polymer portion of the seal should be approximately 30 percent of its original thickness in order to provide an adequate seal. This specification, along with the 0.050 inch maximum door deflection, allows calculation of the seal dimensions and spring stiffness.

In order to facilitate a lock design, the maximum travel of the locking side of the door must be less than two inches after the hinged side of the door makes initial contact with the seal. In order to accomplish this, the total thickness of the section of the seal adjacent to the hinges was reduced by decreasing the diameter of the enclosed spring and increasing its stiffness so that the sealing force did not change. Thus, the initial contact between the door and the seal is postponed until after the clearance between the outer sealing surfaces is reduced to within two inches. This reduces the final compression upon the seal on the hinged side of the door, necessitating the higher stiffness.

Calculations used to establish the spring diameters follow:

From Figure 11, the thickness of the polymer portion of the seal at the contact point is 0.25 inches.

$$\Delta t_{poly} = 2(30\%)(0.25) = 0.15 \text{ inches}$$

This is the total deflection of the polymer. The spring deflection is chosen so that the maximum door deflection is no more than 20% of the total spring compression.

$$\Delta t_{spr} = 0.05/0.2 = 0.25 \text{ inches}$$

The total seal deflection is the sum of the polymer and spring deflections.

$$\Delta t_{total} = 0.25 + 0.15 = 0.4 \text{ inches}$$

The radius from the door hinge to the nearest seal is 4.5 inches and to the outer seal is 51.5 inches.

The outer seal is chosen to have a spring diameter of 1.0 inch. Reference 8 provides the amount of force necessary to compress an 80 durometer o-ring by 30% and was therefore used as an approximation for the force required to compress the BAL seal polymer to provide a 30% compression. The force required is 140 pounds per inch of seal length. The spring stiffness required is given by

$$k = F_{compr}/\Delta t_{spr} = 140/0.25 = 560 \text{ lbs/inch per inch of seal length}$$

The amount by which the inner spring can be compressed in order to prevent more than two inches of travel along the outer spring after initial contact of the inner spring is obtained by solving the equation

$$(t_{spr} - 2(0.3)(0.25))(51.5/4.5) = 2 \text{ inches}$$

$$t_{spr} = 0.025 \text{ inch}$$

The stiffness of the inner spring is

$$k = F_{compr} / t_{spr} = 140/0.025 = 5700 \text{ lbs/inch per inch of seal length}$$

Since the compressed thickness of the spring must be the same around the entire circumference of the door, 0.75 inches, the free diameter of the inner spring is

$$0.75 + t_{spr} = 0.775 \text{ inches}$$

The cross-section of the polymer portion of the seal remains uniform around its entire length and can be molded as a single piece. However, since the enclosed spring has a larger diameter along the outside of the door than along the inside, the spring tapers linearly from the smaller diameter of 0.775 inches to the larger diameter of one inch along the top and bottom of the door.

When the door is closed, the seal is completely enclosed within a rectangular gland 2.5 inches wide by 1.1 inches deep. The gland depth is equally divided between the hatch door and the flange, i.e., the gland is 0.55 inches deep on each of the surfaces. This gland allows the seal to be completely confined when the door is closed, providing for a more equal distribution of sealing pressure over the entire seal and protecting the seal from floating dust particles which would tend to abrade it. The gland also maintains the position of the seal relative to the door, preventing the seal from slipping out of place with repeated use. It also prevents lateral displacement of the seal due to side loading when pressurized, yet allows enough lateral clearance to protect against extrusion of the seal between the door and sealing surface when the door is closed. The seal is attached by means of clips to the flange side of the gland, making it easy to install and replace as a single unit.

Use of the resistance wire to maintain the seal at a minimum temperature level allows the optimization of the high temperature properties of the seal material without particular concern for the low temperature properties, as long as simple exposure to low temperature, such as would occur during transport to the lunar surface, does not damage the material. However, the seal must be heated before its initial use after installation.

EVACUATION SYSTEM

Three major variables were considered in the design of the vacuum system: the amount of atmosphere lost each time the airlock is cycled, the time the astronauts must wait within the airlock while it is being evacuated, and the total weight of the complete vacuum system which must be transported to the lunar surface. These variables are obviously interrelated, and the optimum evacuation system is a trade off among them.

The evacuation time computation for the system is extremely complex because the pumping speed of mechanical vacuum pumps is always a function of inlet pressure. The time required to evacuate a chamber is described by the equation

$$t = V \int_{P_1}^{P_2} dP/(SP)$$

where t = evacuation time

P_1 = initial pressure

P_2 = ultimate pressure

S = pumping speed (volume displacement per unit time)

V = vacuum chamber volume.

The value of S as a function of pressure must be determined experimentally and is usually provided by the vendor in graphical form.

In order to determine the evacuation time for a number of different pump configurations and pressure ranges, a computer program was written which performs the necessary integration numerically. A copy of this FORTRAN program is contained in Appendix 2. The program uses S data read from a data file which consists of sets of points taken from individual pump performance curves. The program also reads the pump weight in order to provide a system weight along with the evacuation time.

Figure 22 shows a graph of evacuation time vs. evacuation system weight and atmosphere loss for a number of system configurations. The graph was generated using the program mentioned above and pump performance data taken from Reference 5. The analysis was constrained to the working pressure range of standard mechanical pumps, i.e., rotary vane and rotary piston types, which can achieve ultimate pressures down to 1 millibar.

The plot of Figure 22 shows that neither the pumping time nor the weight of the evacuation system undergoes large changes in response to changes in ultimate airlock pressure, which determines air loss. As a result, the lower extreme of 1 millibar was chosen. Using an ultimate pressure in the airlock before venting of 1 millibar, the airlock can be cycled approximately forty times before losing one pound-mass of air. This was considered an acceptable loss in order to maintain the simplicity, maintainability, and speed provided by a mechanical pumping system.

To choose the most suitable system, the maximum acceptable evacuation time was determined and the lightest system capable of this time was selected. Using the curve of Figure 22, the effects of incremental changes in the evacuation time of the system upon the system weight were investigated in order to determine the advantages of adjusting the pumping time slightly in either direction.

CLEANING SYSTEM

The air hoses utilized in the cleaning system have a diameter of one and one-half inches. The radial blower is one foot in diameter and operates at 3450 rpm with a flow rate of 400 cubic feet per minute. A one horsepower motor is used to operate the blower. The calculations used in sizing the blower are as follows:

Volume Flow Rate, $Q = VA$

where V = desired speed = 4000 ft/min

A = cross-sectional area at exit from hose of diameter of 3 inches

$Q = 4000(\pi)(1.5^2)(2 \text{ hoses}) = 400 \text{ ft}^3\text{/min} = 6.67 \text{ ft}^3\text{/sec}$

Calculation of Blade Diameter:

Power, $P = \eta \dot{m} H = \rho Q H$

where H = Head = U^2/g_c for an ideal blower with no prewhirl

U = tip velocity = (blade radius)(rotational speed) = Rw

g_c = gravitational constant = 32.2 ft/sec^2

Desired rotational speed, N = 3450 rpm

w = 361.28 rad/sec

$U = R(361.28)$

Desired power, P = 1 hp = 550 ft-lbf/sec

Efficiency, η = 85%

$P = \eta \rho Q U^2 / g_c$

$550 = (.85)(0.07535)(6.67)(361.28R)^2$

$R^2 = 0.3176\ ft^2$

$R = 0.56\ ft$

$D = 1.12\ ft = 13.5\ ft$

The high velocity air flow from the hoses allows for turbulent flow over the surface of the spacesuits, thereby causing the fine lunar dust particles to be fluttered off the spacesuits. Air hoses were chosen as they may be used by the astronauts like a shower head to remove particles and can access areas difficult to clean, such as creases in the spacesuit and floor corners. Stored compressed air from the lunar base module is ducted into the airlock via the hoses. The maximum allowable levels of contaminants for the lunar base are not yet determined. As a result, the HEPA filter was chosen because it effectively cleans the air of all particles 0.0003 millimeters or larger with 99% efficiency, an acceptable standard for many commercial uses, including hospital clean rooms.

The cleaning system equipment was placed below the floor level for easy accessibility for maintenance. The three sections of floor grating can be lifted by the astronauts to expose the equipment in order to clean the filters or make any necessary repairs. Additionally, the airlock can be pressurized to allow repairs to be made by the astronauts without spacesuits.

COST AND VOLUME ANALYSIS

The cost analysis was performed on the various components of the total airlock system and was divided into costs required for material, labor, and transportation. A break-up of the analysis for each component is contained in Appendix 3. The total material/hardware cost for each component is as follows:

Airlock Module	$ 4046
Hatch Modules	2676
Grating	404
Hinges	4000
Locking Mechanism	6000
Seals	6000
Evacuation System	11800
Cleaning System	905
Total	$ 35831

Estimated labor costs, including installation only for the hinges, evacuation system and cleaning system, is $74,000.

Estimated cost for transportation to the lunar surface, calculated for a total weight of 7128 lbs is $156,820, 400.

Total cost for the entire project: <u>$156,930,231</u>

Volume occupied by the airlock system, assuming cleaning equipment is housed inside, is as follows:

Airlock Module	725 ft^3
Hatch Module (2)	104
Evacuation System	13
Total	842 ft^3

CONCLUSIONS AND RECOMMENDATIONS

All objectives initially identified for this project were met in the final design.

Perhaps the most difficult aspect of the airlock design stems from the intimate interaction among the components of which it is comprised. No single design can be attempted without careful consideration of its effects upon each of the other components and upon the airlock as a complete unit. In addition, a relative priority must be attached to each of the many design constraints, and changing the priority of even a single constraint greatly influences the design of the entire system. Thus, the design variables to be optimized must be selected up front, and no single design is optimum under every operating condition.

The most important design constraints are the weight of the airlock system and the amount of time the astronauts must wait during each airlock cycle. Most of the waiting time occurs, as mentioned previously, while the airlock is being evacuated and the total evacuation time required to transfer a large number of astronauts is approximately the same whether they are transferred through a large airlock in a single cycle or through a smaller airlock in several cycles. However, there is a certain overhead of time associated with entering and leaving the airlock: closing and securing the hatch doors and cycling the cleaning and filtration system. When transferring large numbers of astronauts, the waiting time due to these factors can become significant. This can be reduced by increasing the size of the airlock, i.e., reducing the number of airlock cycles required per astronaut. However, this is done at the expense of a large increase in weight, as well as a large increase in unnecessary evacuation time if the airlock is cycled at less than its full capacity.

The size of the airlock also depends upon the size of the astronauts and the amount of equipment they carry through the airlock module. Obviously, increasing the size of the airlock increases its versatility and adaptability to changing performance requirements, but, again, at the expense of increased weight and evacuation time.

The design options for the hatch and locking mechanism are severely limited by the seal technology. Dynamic seals allow unacceptable leakage and require tolerances which are too small to accommodate lunar temperature variations. Thus, the door cannot move tangentially to the seal and a substantial normal force must be applied to the door in order to seat it properly. If, however, the amount of leakage considered acceptable is increased or the module temperature is controlled using an environmental control system, dynamic seals might become feasible and a more complex hatch door design would be possible. Figures of alternative hatch door designs initially considered in this project are contained in Appendix 4-C.

The kinematics of the hatch were also constrained by the need to protect the seal. If the seal were self-aligning or the locking mechanism could provide a path of motion which would not damage the seals, the door would sweep out a smaller area and allow easier navigability of the airlock. Unfortunately, such designs are very complex and unwarranted unless navigability is high priority.

The amount of compression required in order to protect the seal against back pressure depends upon the amount of deflection the door undergoes when this pressure is applied. Increasing the stiffness, and therefore the weight of the door, reduces the amount of force required to compress the seal. In turn, the weight and complexity of the locking mechanism and the effort required to close the door are also reduced. Once again, the optimum trade off depends upon the relative priorities of the design paramenters.

The geometry of the airlock lends itself easily to construction in symmetric sections. The sections could be joined by gasketed flanges in lunar orbit or on the lunar surface and thereby could be shipped disassembled in order to conserve space. The components of the airlock could be assembled within the cargo bay of the transport vehicle in order to minimize radiation exposure during the initial phases of lunar settlement, or it could be assembled easily on the surface. Since all of the field joints are bolted, assembly would require no special tools or skills.

During the course of the design process, several factors were of necessity neglected or simplified due to the time constraints placed upon the project. The rib support patterns of both the airlock module and hatch module were based largely upon experience and intuition of the designers. While these designs satisfy the required structural requirements, a more detailed analysis should be performed to minimize the total weight of the supports required to satisfy these constraints. Likewise, the material assumed for the ribs was chosen to be aluminum for consistency; however, other materials such as fiber reinforced composites and even high alloy steels might be investigated to see if higher strength-to-weight ratios could be obtained.

Because of its easy availability, light weight, and workability, aluminum was chosen as the material for the actual shell of the module. Several alternatives to aluminum were considered, including a flexible structure, such as a fabric covering, attached to a supporting framework. Due to the difficulty in obtaining information within the design period, this option was not pursued, although it shows considerable promise.

Many of the components of the design were chosen from off-the-shelf equipment available from vendors. For a lunar settlement, however, the benefits of designing special purpose equipment of lighter materials and different dimensions could outweigh the costs in most cases, since the design priorities required are obviously very different on the lunar surface. The weight of such standard items as vacuum pumps, motors, and blowers could be dramatically decreased.

Finally, some sort of fail safe mechanism is necessary to prevent opening of both hatch doors at the same time, thereby venting the entire module atmosphere to the lunar surface. Several mechanical interlocks which prevent one lock from being opened while the other is not latched were considered, but time constraints prevented development of a design.

ACKNOWLEDGEMENTS

We greatly appreciate the information and assistance received from the following individuals and organizations:

Mr. James W. Brazell, Mechanical Engineering, Georgia Tech

Mr. Vince Casissi, NASA, Kennedy Space Center

Mr. Gene T. Colwell, Mechanical Engineering, Georgia Tech

Mr. John P. DeVeaux, U. S. Army Corps of Engineers

Mr. John Keller, Daro Industries, Inc., 859-T N. Prior Avenue, St. Paul, MN 55104 (612)-646-6771

Mr. Brice MacLaren, Mechanical Engineering, Georgia Tech

Mr. Dennis Matthews, NASA, Kennedy Space Center

Mr. Gary McMurray, Mechanical Engineering, Georgia Tech

Mr. Mike Richardson, Phoenix Metals Co., Atlanta, Georgia, (404)-622-8136

Mr. Dennis Ricks, National O-Ring Company, 1-800-421-3837

Mr. Pat Ruetschle, Structural Design Research Corporation, 2000 Eastman Drive, Milford, Ohio 45250

Mr. Stephen Smith, CAE/CAD Laboratory, Georgia Tech

Mr. Ron Uranko, Leybold-Heraus Vacuum Products, Inc., 5700 Mellon Rd., Export, PA 15632

Bal Seal Engineering Company, 620 W. Warner Ave., Santa Ana, California 92707 (714)-557-5192

Liberty Industries, Inc., 1-800-828-5656

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10. Shigley, Joseph E. and Uicker, John J., Jr., Theory of Machines and Mechanisms, McGraw-Hill Book Company, New York, New York 1980.

FIGURES

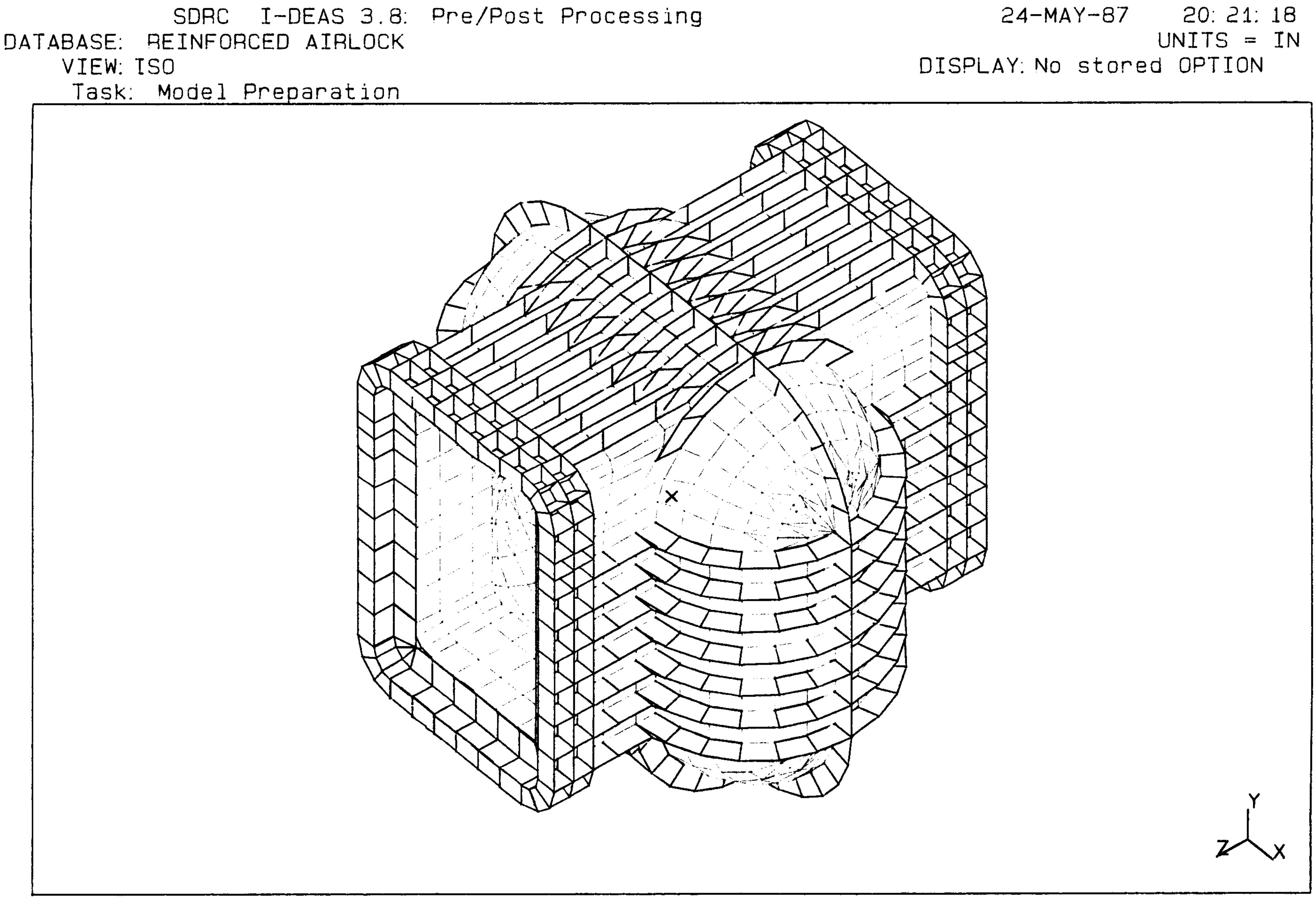
SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: REINFORCED AIRLOCK
VIEW: ISO
Task: Model Preparation
24-MAY-87 20: 21: 18
UNITS = IN
DISPLAY: No stored OPTION
Y
Z
X

Figure 1

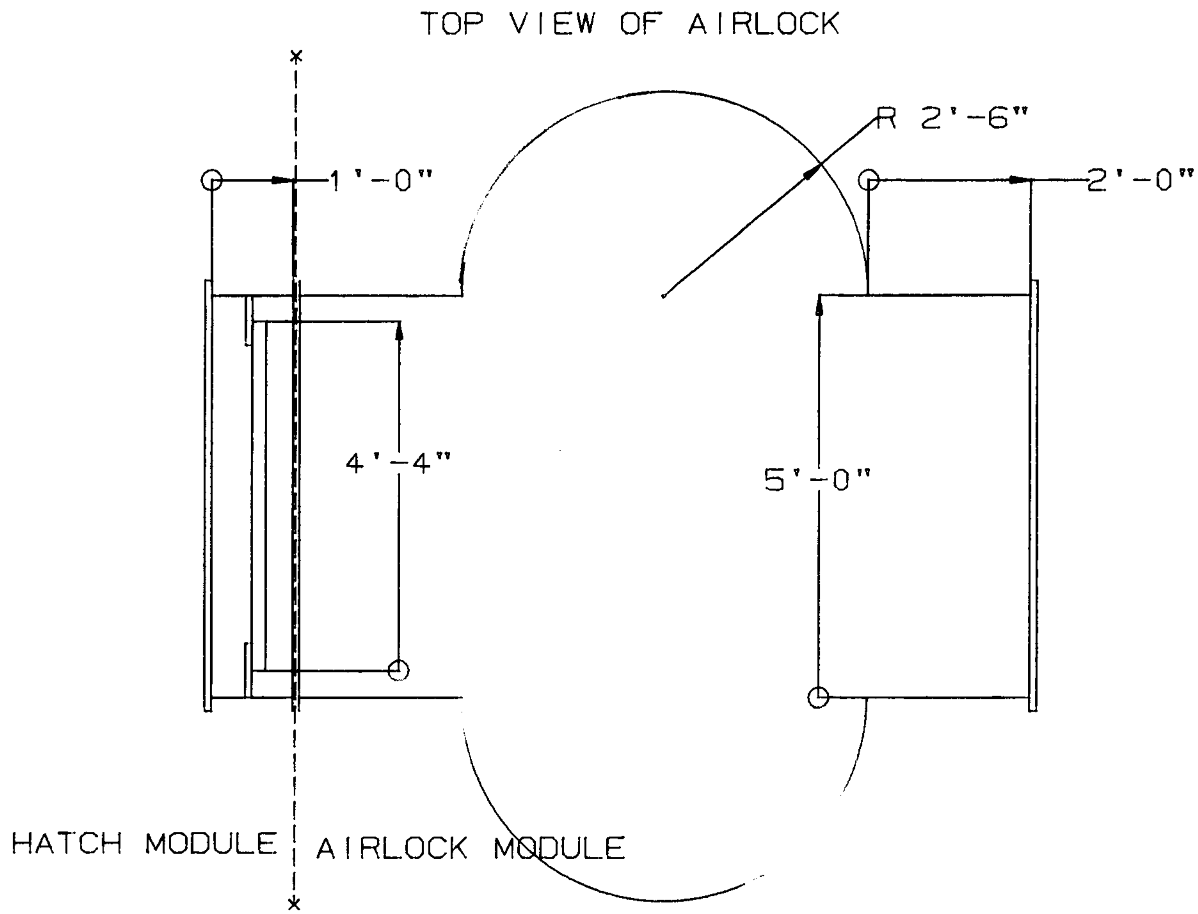
TOP VIEW OF AIRLOCK
R 2'-6"
1'-0"
2'-0"
4'-4"
5'-0"
HATCH MODULE
AIRLOCK MODULE

Figure 2

GT20 87/06/04. 06.28.07. ARJN

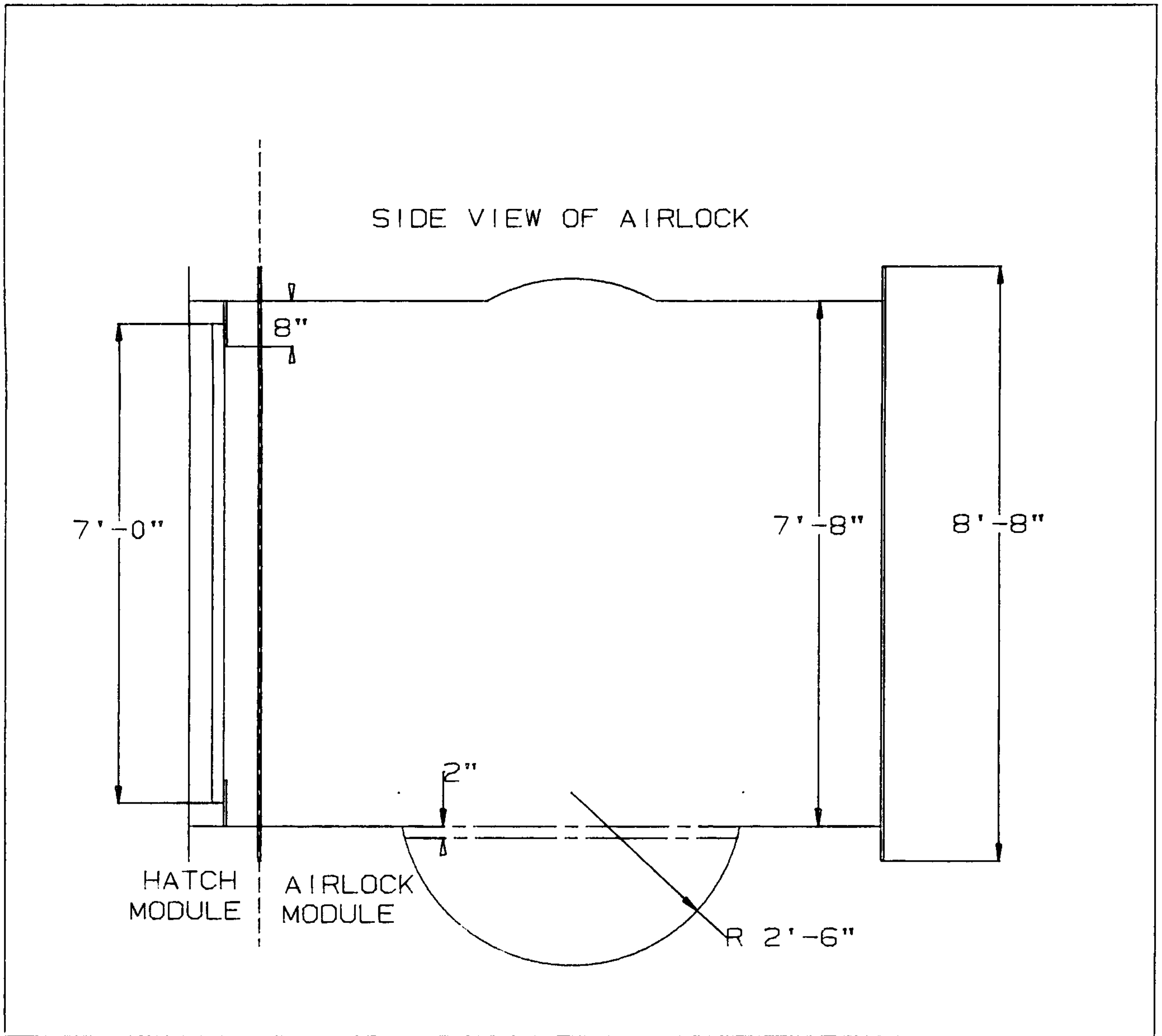
SIDE VIEW OF AIRLOCK
8"
7'-0"
7'-8"
8'-8"
2"
HATCH
MODULE
AIRLOCK
MODULE
R 2'-6"

Figure 3

GT20 87/06/03. 21.16.24. AMXF

FRONT VIEW OF AIRLOCK SHOWING CLEAN ROOM

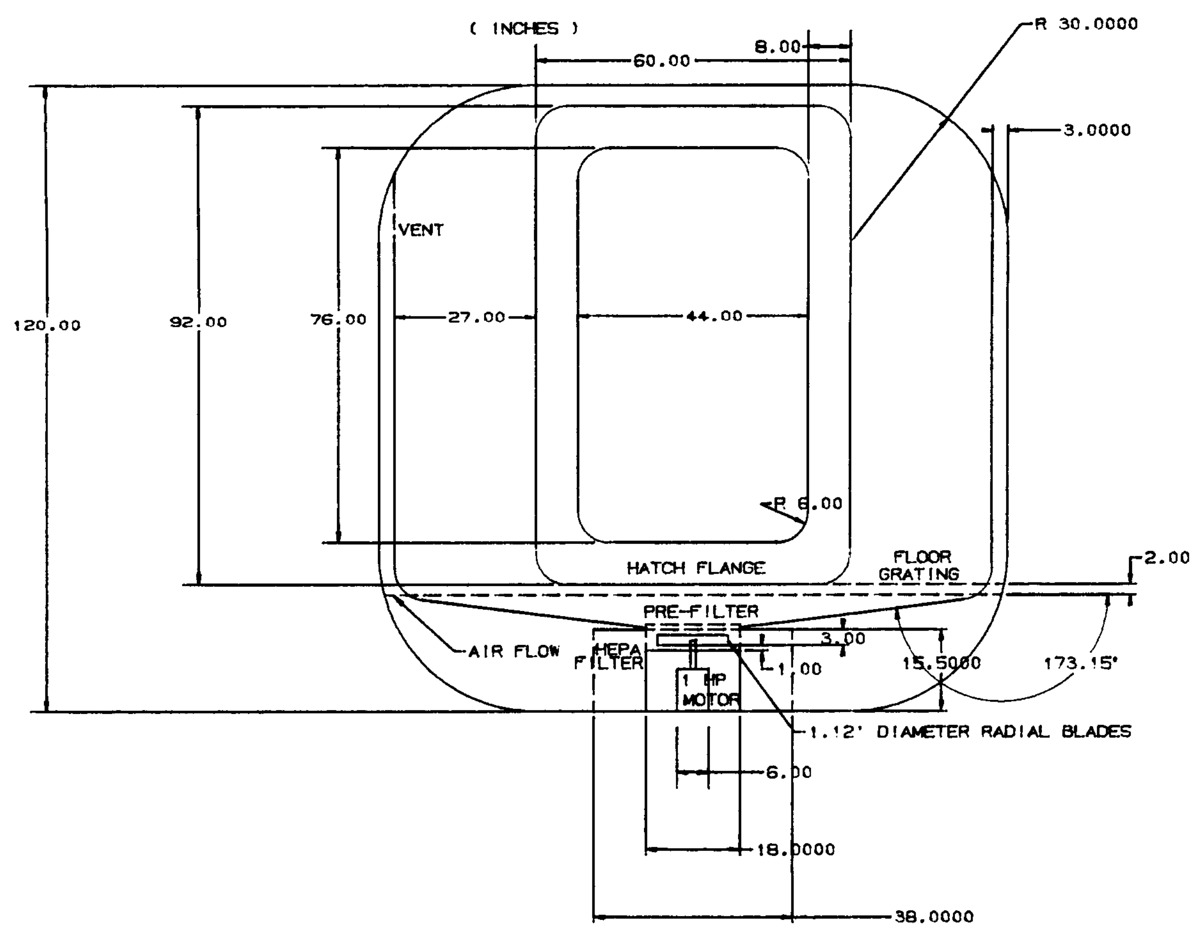

Figure 4

GT93 87/06/04. 12.09.55. ATSQ

VACUUM SYSTEM SCHEMATIC

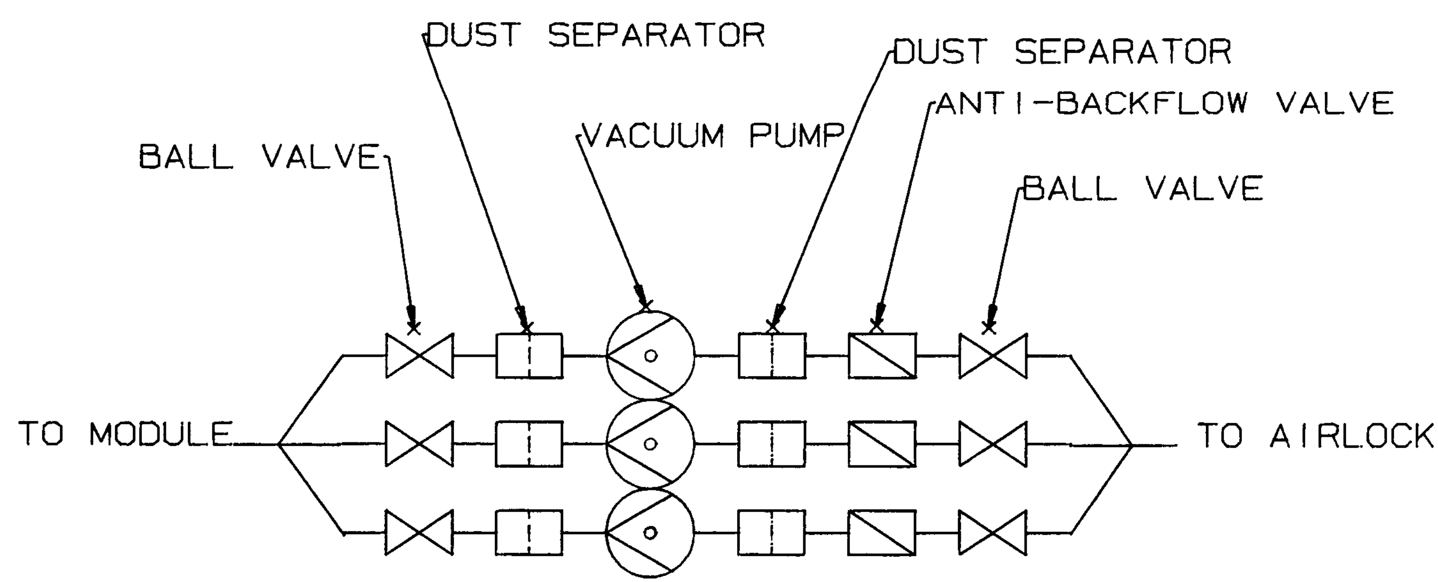

Figure 5

GT93 87/06/04. 10.24.22. ASAL

SDRC I-DEAS 3.8: Pre/Post Processing
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VIEW: 2, 1, 1
Task: Model Preparation

25-MAY-87 16:24:42
UNITS = IN
DISPLAY: none, none, none

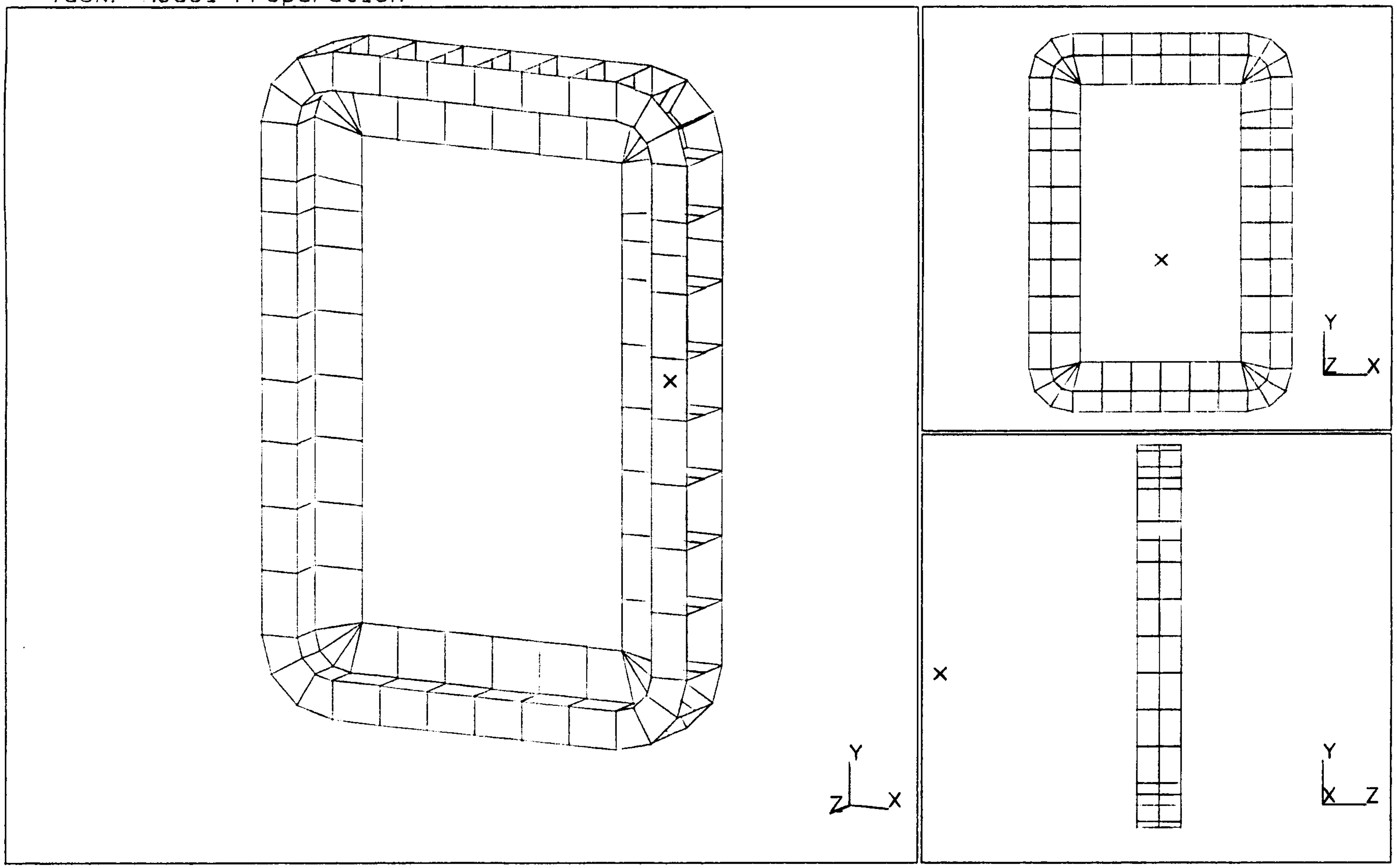


Figure 6

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCHDOOR
VIEW: 1, 3
Task: Model Preparation

21-MAY-87 13:40:54
UNITS = IN
DISPLAY: none, none

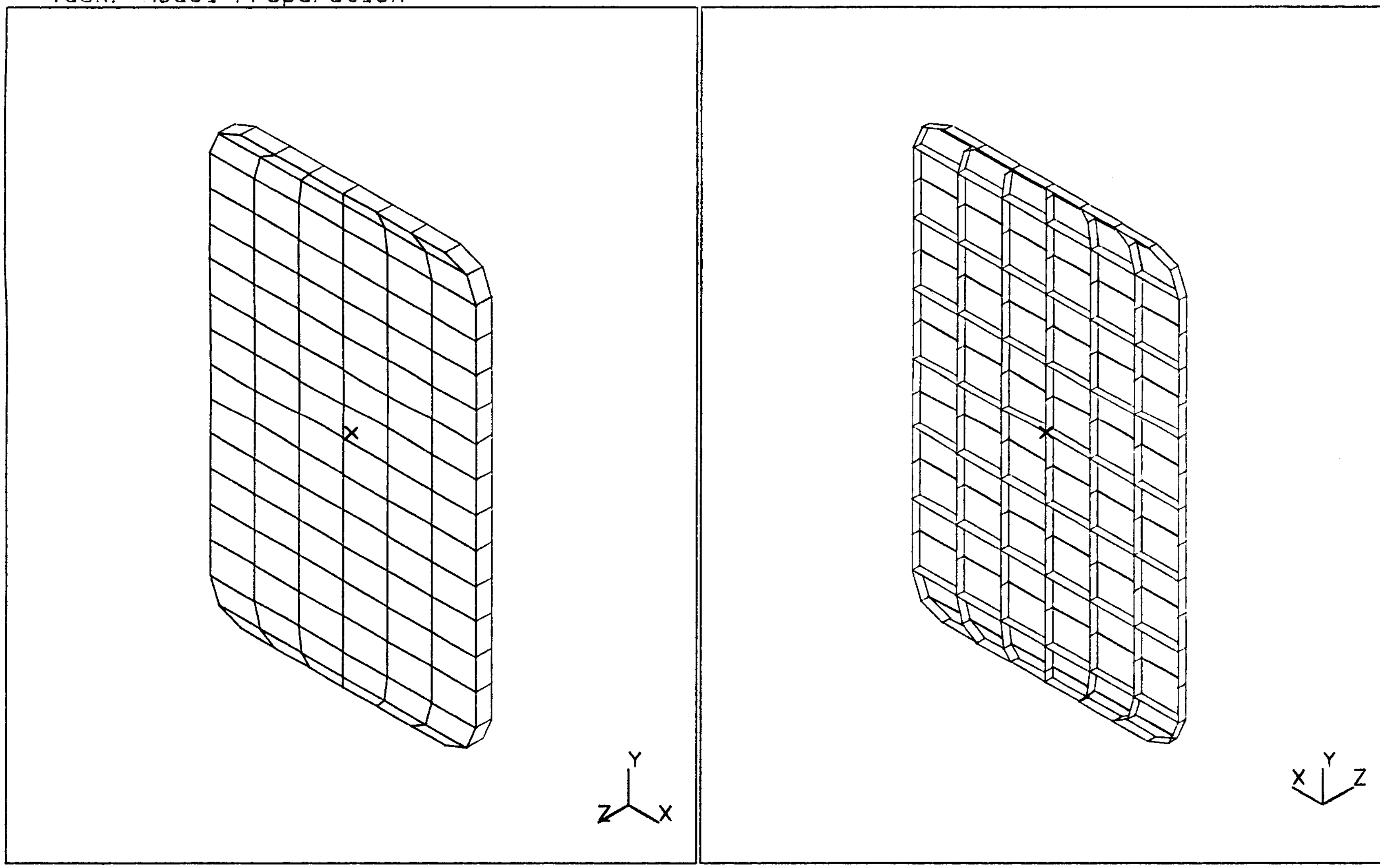


Figure 7

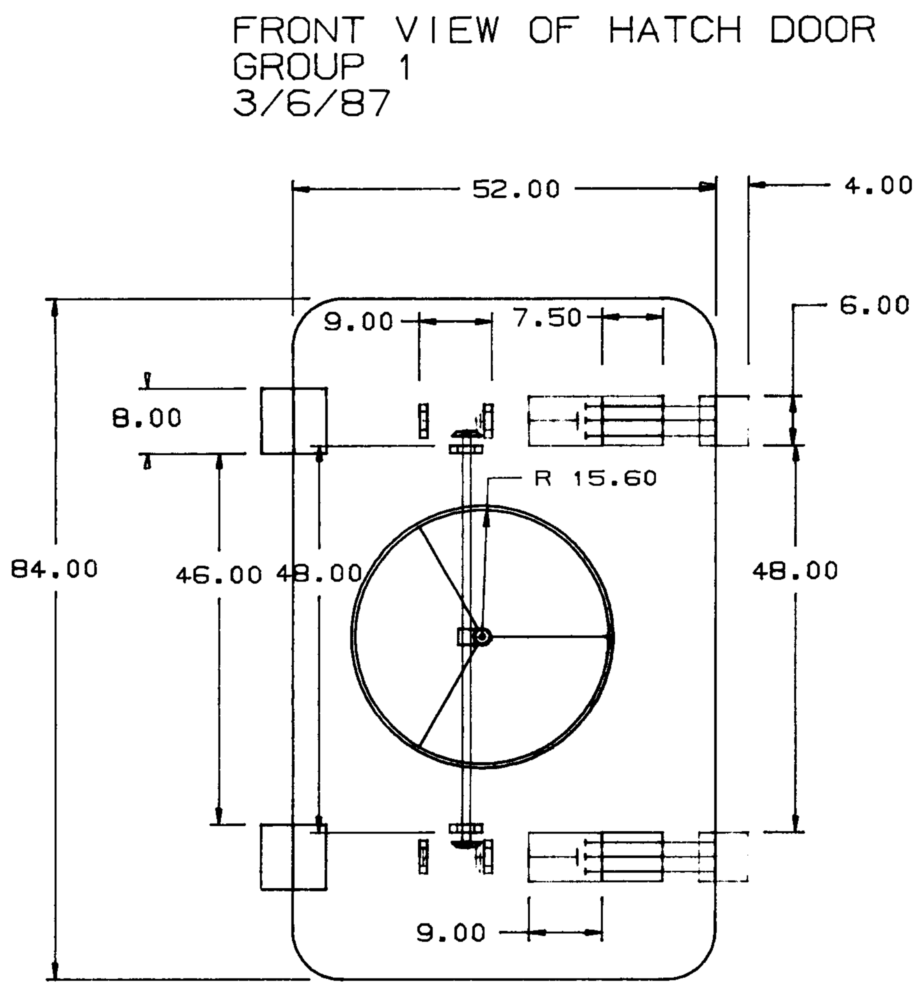

FRONT VIEW OF HATCH DOOR
GROUP 1
3/6/87
52.00
4.00
6.00
9.00
7.50
8.00
R 15.60
84.00
46.00
48.00
48.00
9.00

Figure 8

ISOMETRIC VIEW OF HATCH DOOR
GROUP 1
3/6/87

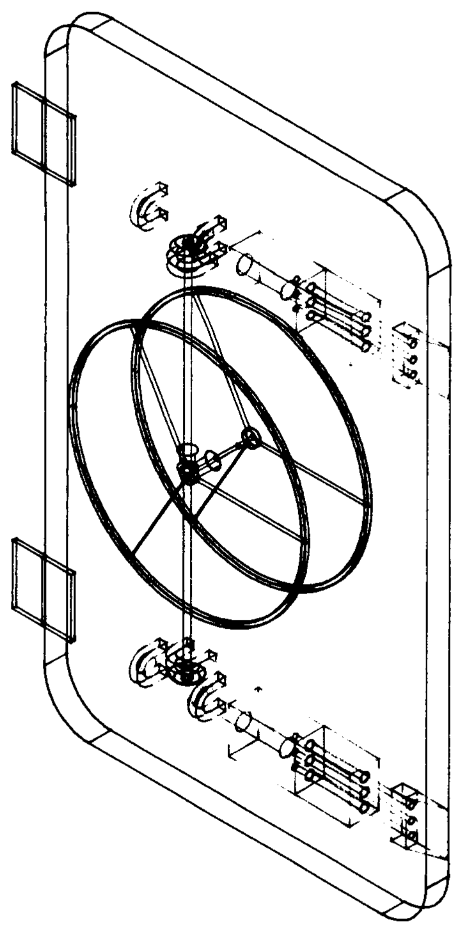


Figure 9

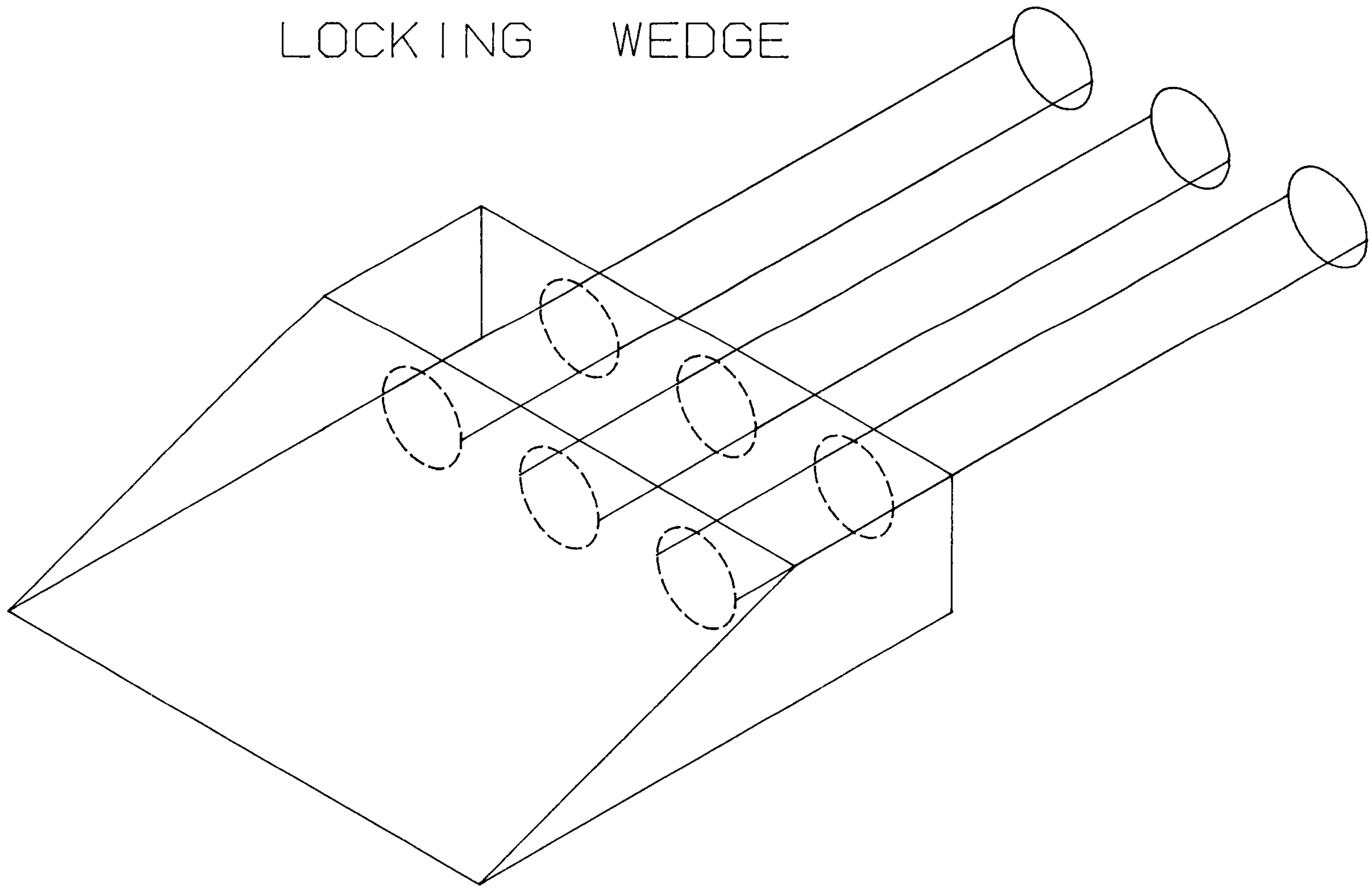


Figure 10

SPRING LOADED SEAL

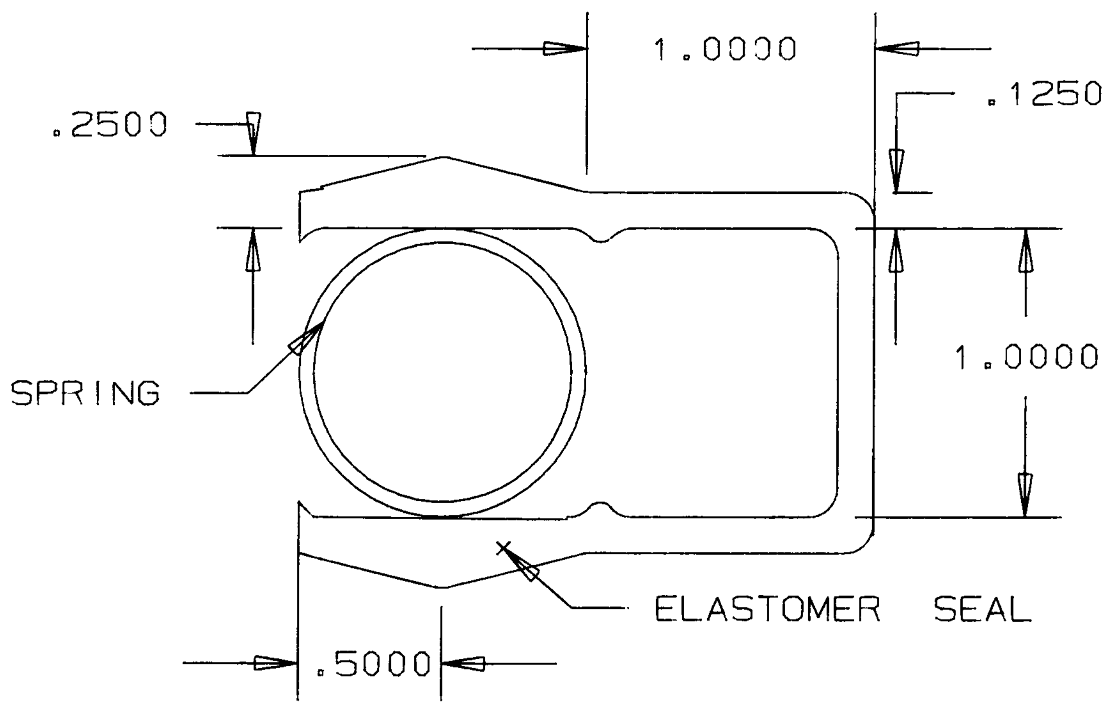


Figure 11

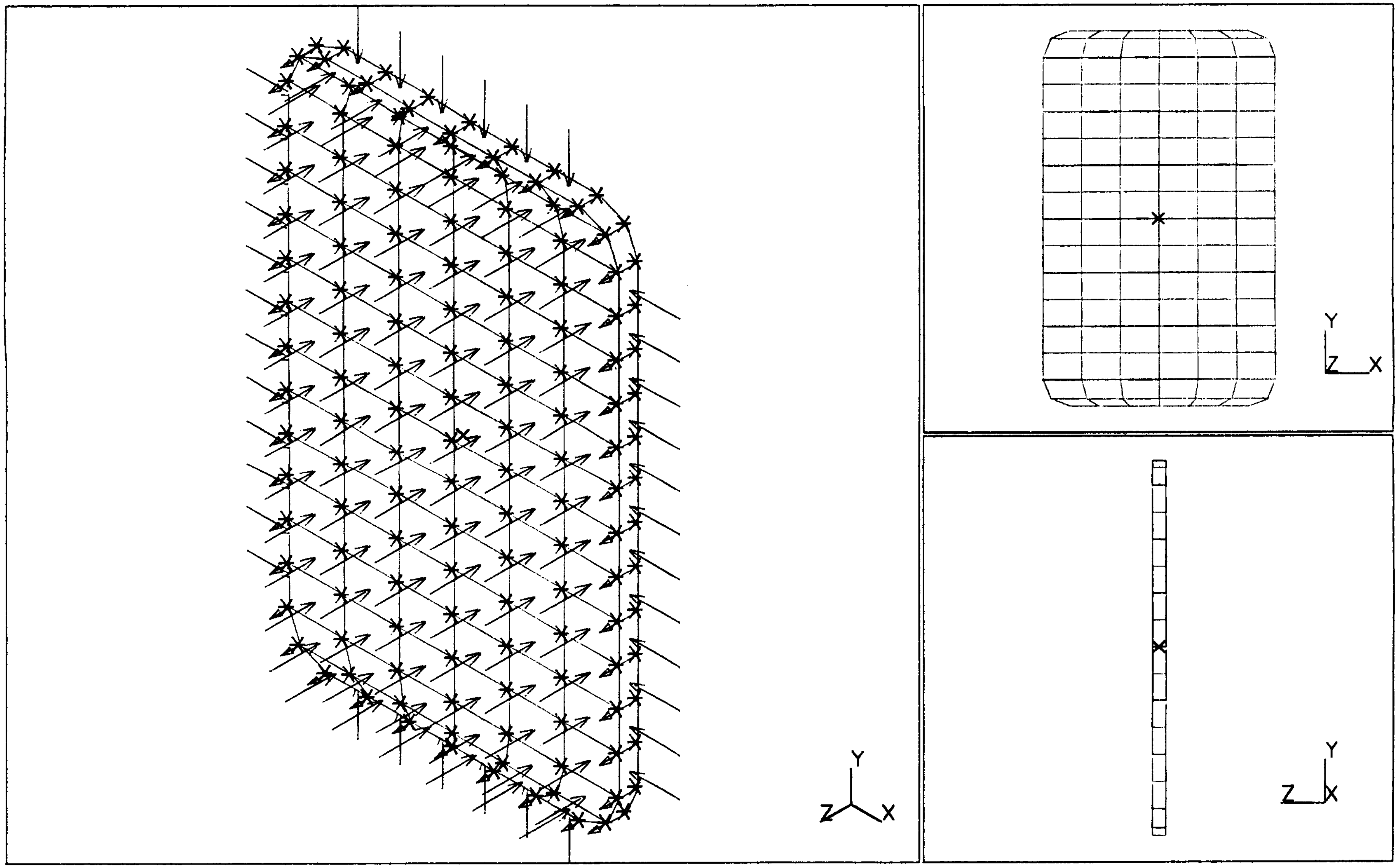
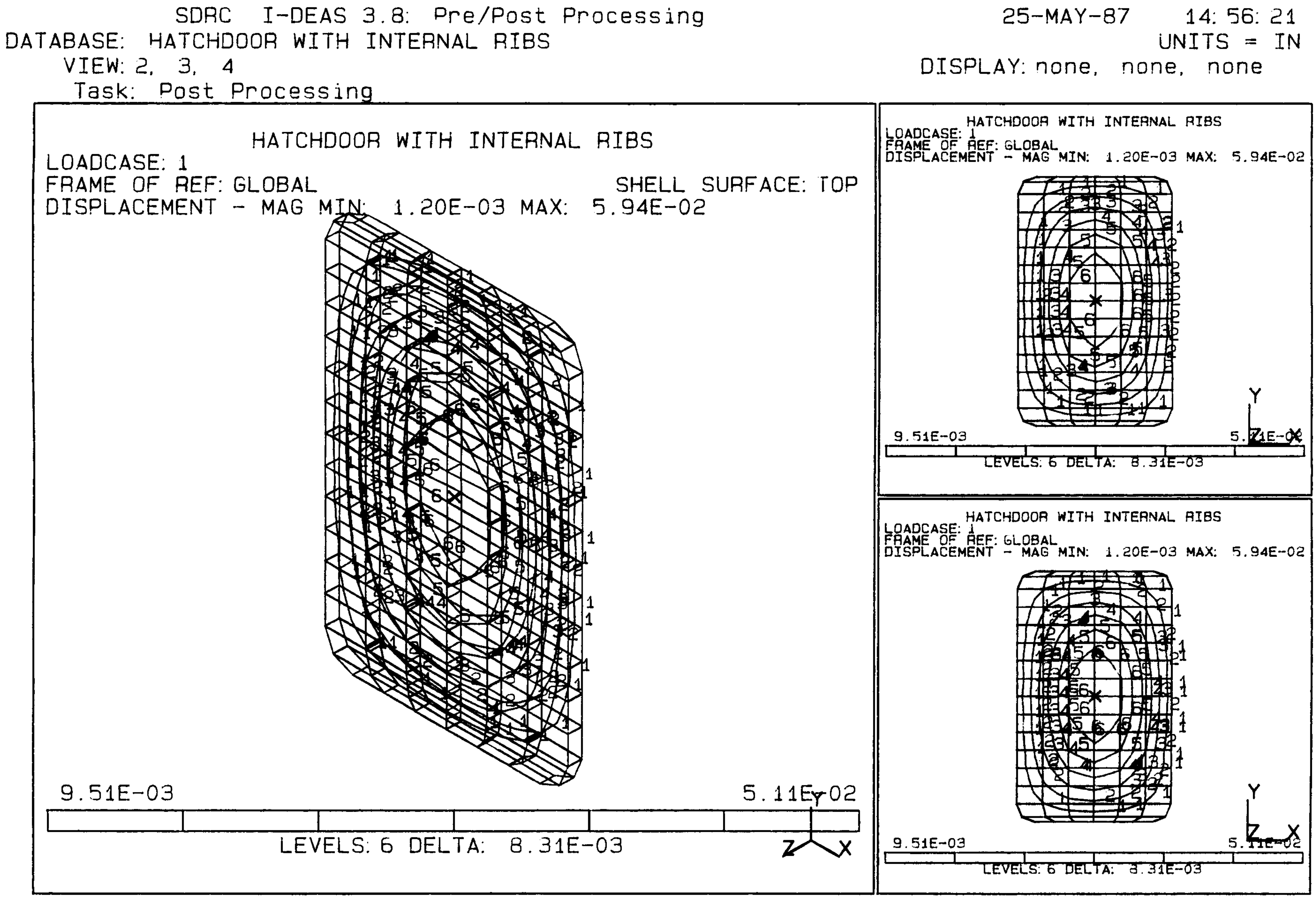


Figure 12



SDRC I-DEAS 3.8: Pre/Post Processing
25-MAY-87 14:56:21
DATABASE: HATCHDOOR WITH INTERNAL RIBS
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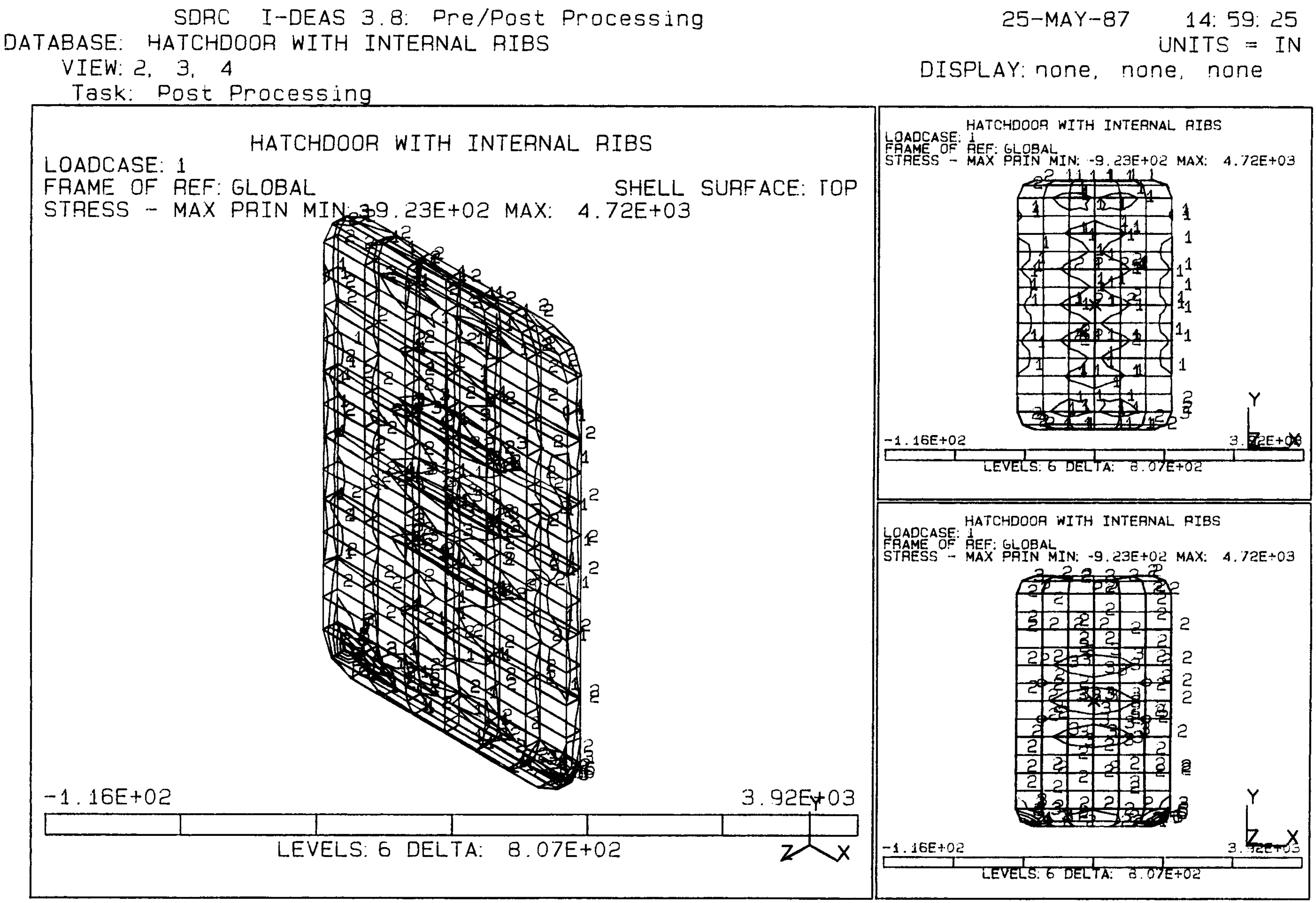
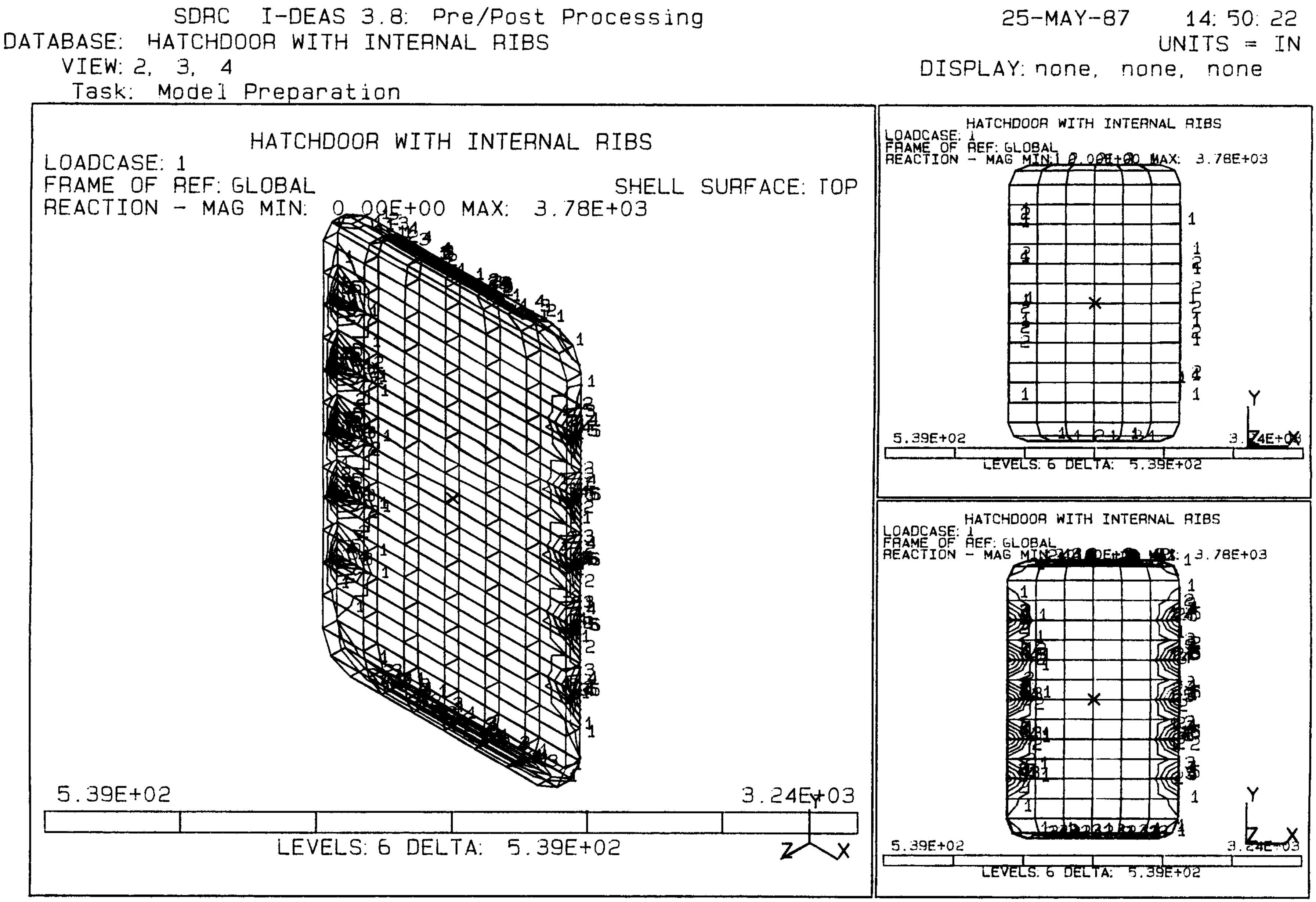
VIEW: 2, 3, 4
DISPLAY: none, none, none
Task: Post Processing
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
DISPLACEMENT - MAG MIN: 1.20E-03 MAX: 5.94E-02
9.51E-03
5.11E-02
LEVELS: 6 DELTA: 8.31E-03
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
DISPLACEMENT - MAG MIN: 1.20E-03 MAX: 5.94E-02
9.51E-03
LEVELS: 6 DELTA: 8.31E-03
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
DISPLACEMENT - MAG MIN: 1.20E-03 MAX: 5.94E-02
9.51E-03
LEVELS: 6 DELTA: 8.31E-03

Figure 13



SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCHDOOR WITH INTERNAL RIBS
VIEW: 2, 3, 4
Task: Post Processing
25-MAY-87 14:59:25
UNITS = IN
DISPLAY: none, none, none
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
STRESS - MAX PRIN MIN: -9.23E+02 MAX: 4.72E+03
-1.16E+02
3.92E+03
LEVELS: 6 DELTA: 8.07E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -9.23E+02 MAX: 4.72E+03
-1.16E+02
LEVELS: 6 DELTA: 8.07E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -9.23E+02 MAX: 4.72E+03
-1.16E+02
LEVELS: 6 DELTA: 8.07E+02

Figure 14



SDRC I-DEAS 3.8: Pre/Post Processing
25-MAY-87 14: 50: 22
DATABASE: HATCHDOOR WITH INTERNAL RIBS
UNITS = IN
VIEW: 2, 3, 4
DISPLAY: none, none, none
Task: Model Preparation
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
REACTION - MAG MIN: 0.00E+00 MAX: 3.78E+03
5.39E+02
3.24E+03
LEVELS: 6 DELTA: 5.39E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 3.78E+03
5.39E+02
LEVELS: 6 DELTA: 5.39E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
3.78E+03
5.39E+02
3.24E+03
LEVELS: 6 DELTA: 5.39E+02

Figure 15

SDRC I-DEAS 3.8: Pre/Post Processing 27-MAY-87 19:06:50
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VIEW: ISO DISPLAY: No stored OPTION
Task: Analysis Cases

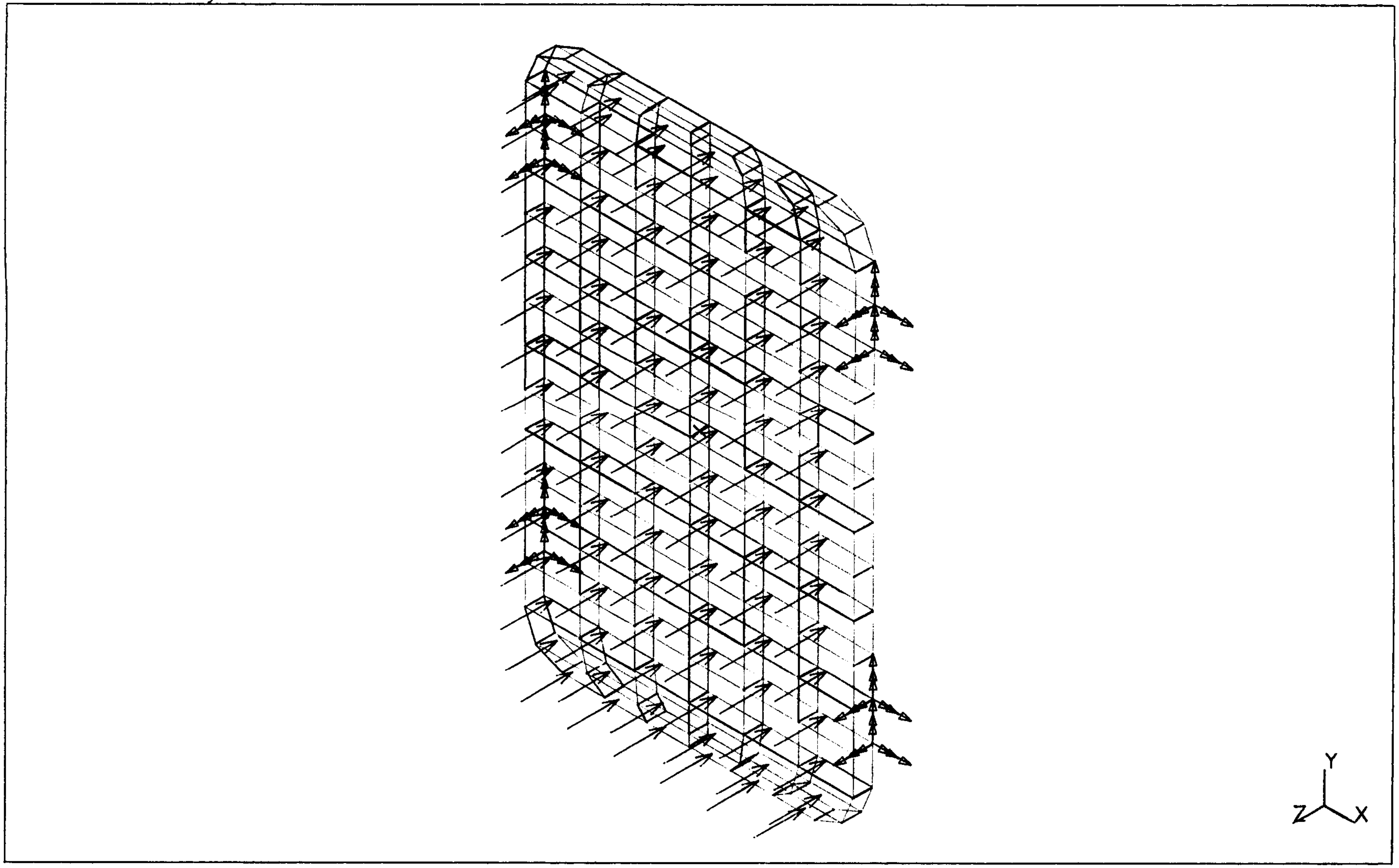


Figure 16

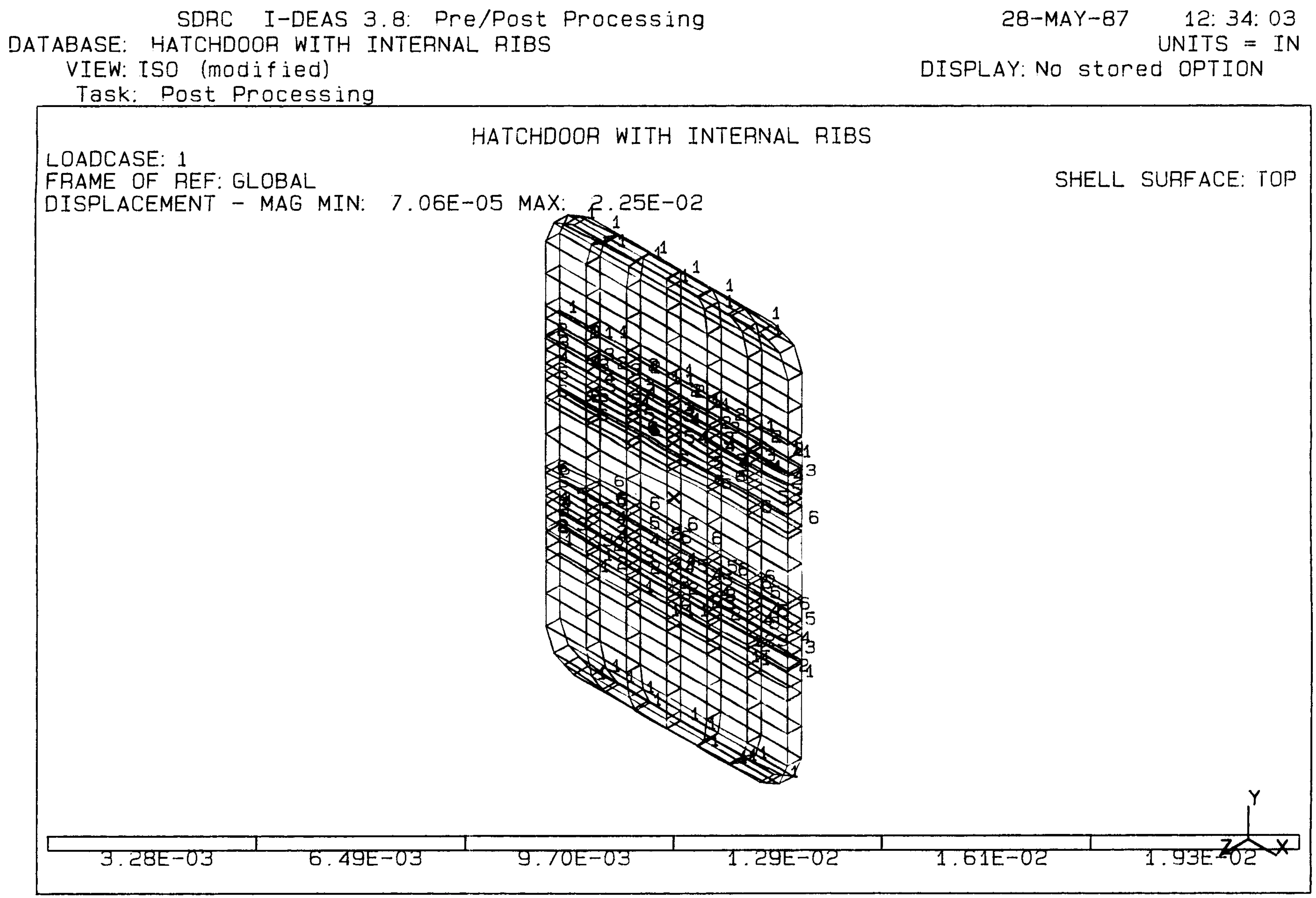
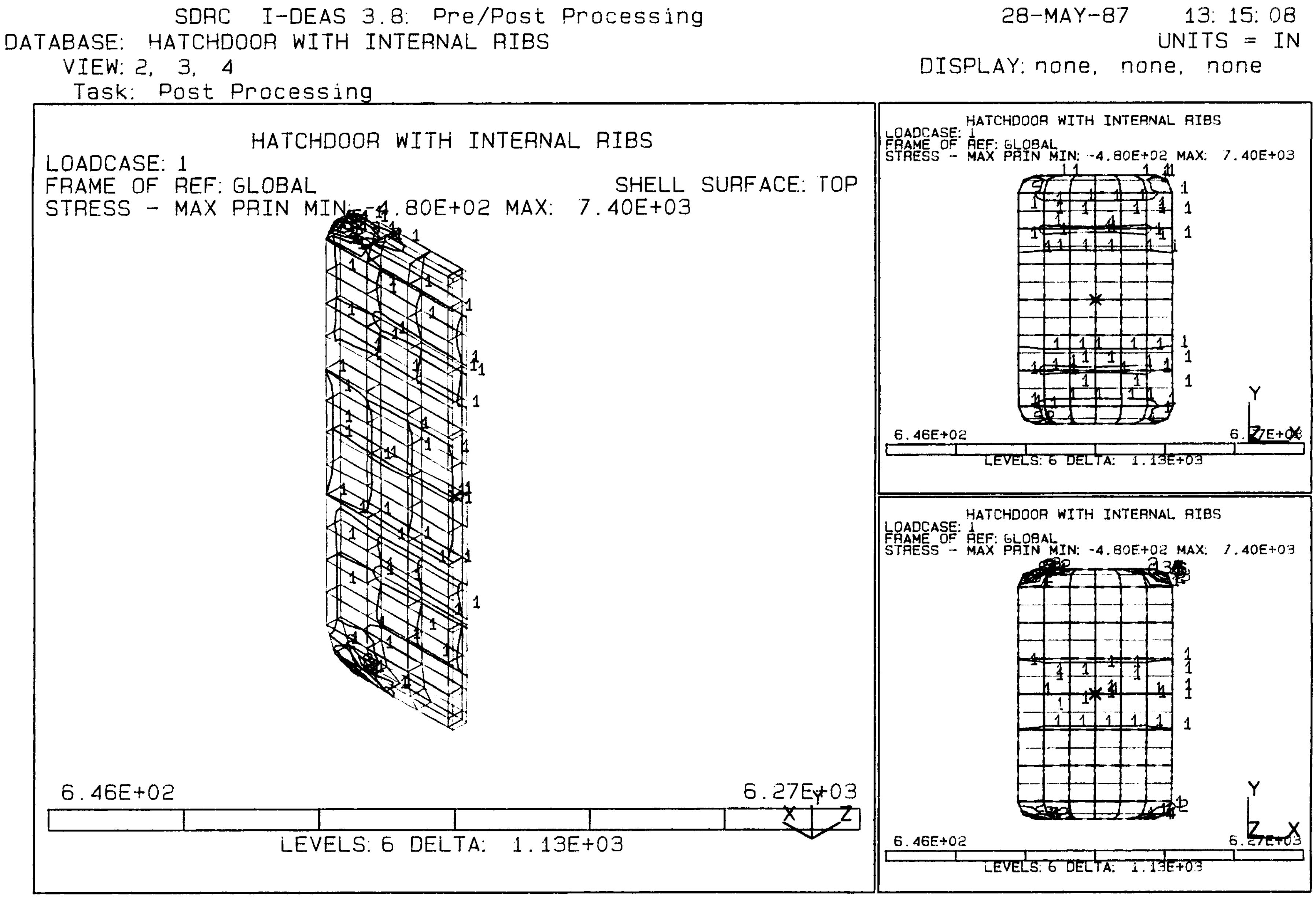
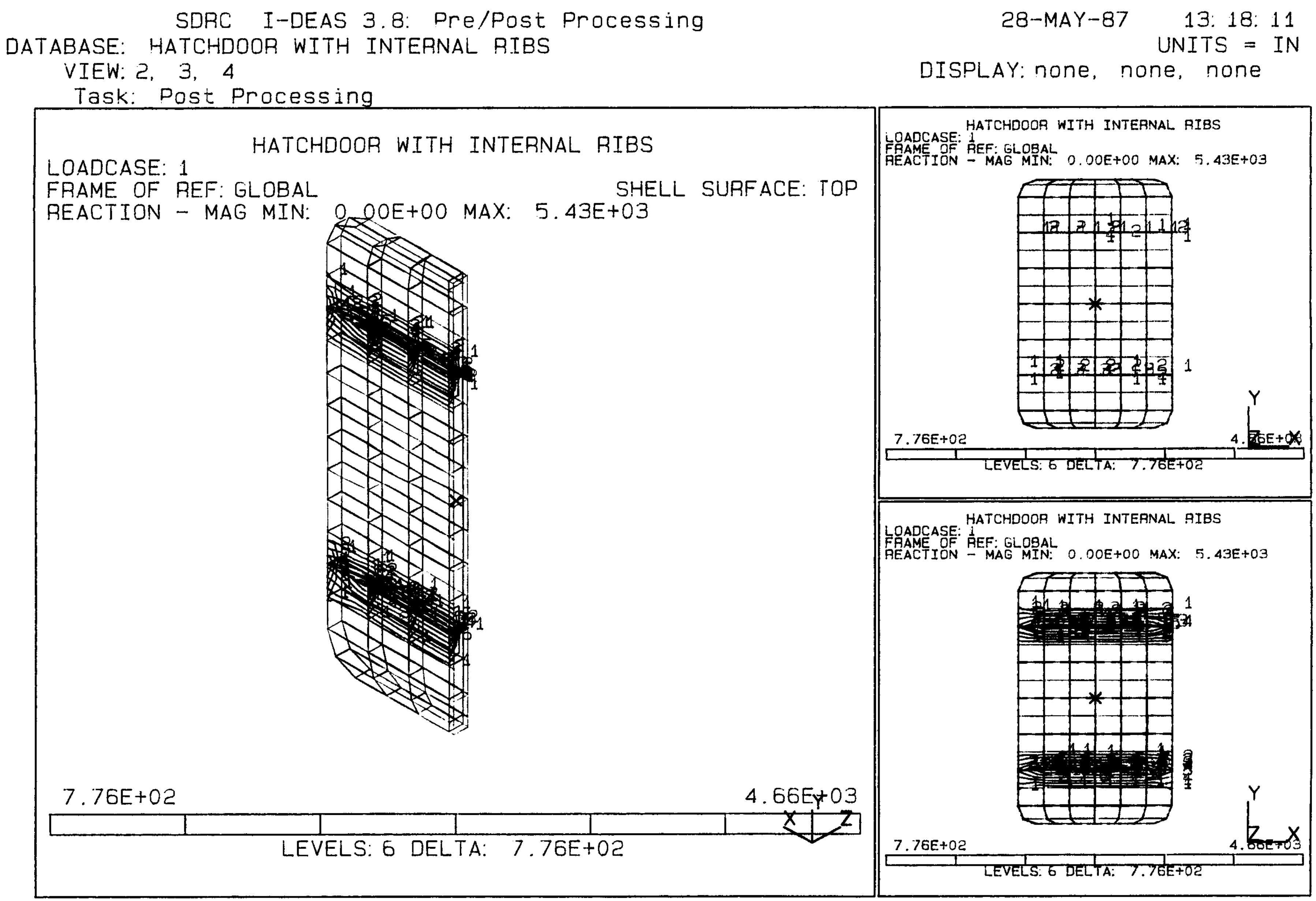

SDRC I-DEAS 3.8: Pre/Post Processing
28-MAY-87 12:34:03
DATABASE: HATCHDOOR WITH INTERNAL RIBS
UNITS = IN
VIEW: ISO (modified)
DISPLAY: No stored OPTION
Task: Post Processing
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
DISPLACEMENT - MAG MIN: 7.06E-05 MAX: 2.25E-02
3.28E-03
6.49E-03
9.70E-03
1.29E-02
1.61E-02
1.93E-02
Y
Z
X

Figure 17



SDRC I-DEAS 3.8: Pre/Post Processing
28-MAY-87 13: 15: 08
DATABASE: HATCHDOOR WITH INTERNAL RIBS
UNITS = IN
VIEW: 2, 3, 4
DISPLAY: none, none, none
Task: Post Processing
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
STRESS - MAX PRIN MIN: -4.80E+02 MAX: 7.40E+03
6.46E+02
6.27E+03
LEVELS: 6 DELTA: 1.13E+03
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -4.80E+02 MAX: 7.40E+03
6.46E+02
LEVELS: 6 DELTA: 1.13E+03
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -4.80E+02 MAX: 7.40E+03
6.46E+02
LEVELS: 6 DELTA: 1.13E+03

Figure 18


SDRC I-DEAS 3.8: Pre/Post Processing
28-MAY-87 13:18:11
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UNITS = IN
VIEW: 2, 3, 4
DISPLAY: none, none, none
Task: Post Processing
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LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
REACTION - MAG MIN: 0.00E+00 MAX: 5.43E+03
7.76E+02
4.66E+03
LEVELS: 6 DELTA: 7.76E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 5.43E+03
7.76E+02
LEVELS: 6 DELTA: 7.76E+02
HATCHDOOR WITH INTERNAL RIBS
LOADCASE: 1
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 5.43E+03
7.76E+02
LEVELS: 6 DELTA: 7.76E+02

Figure 19

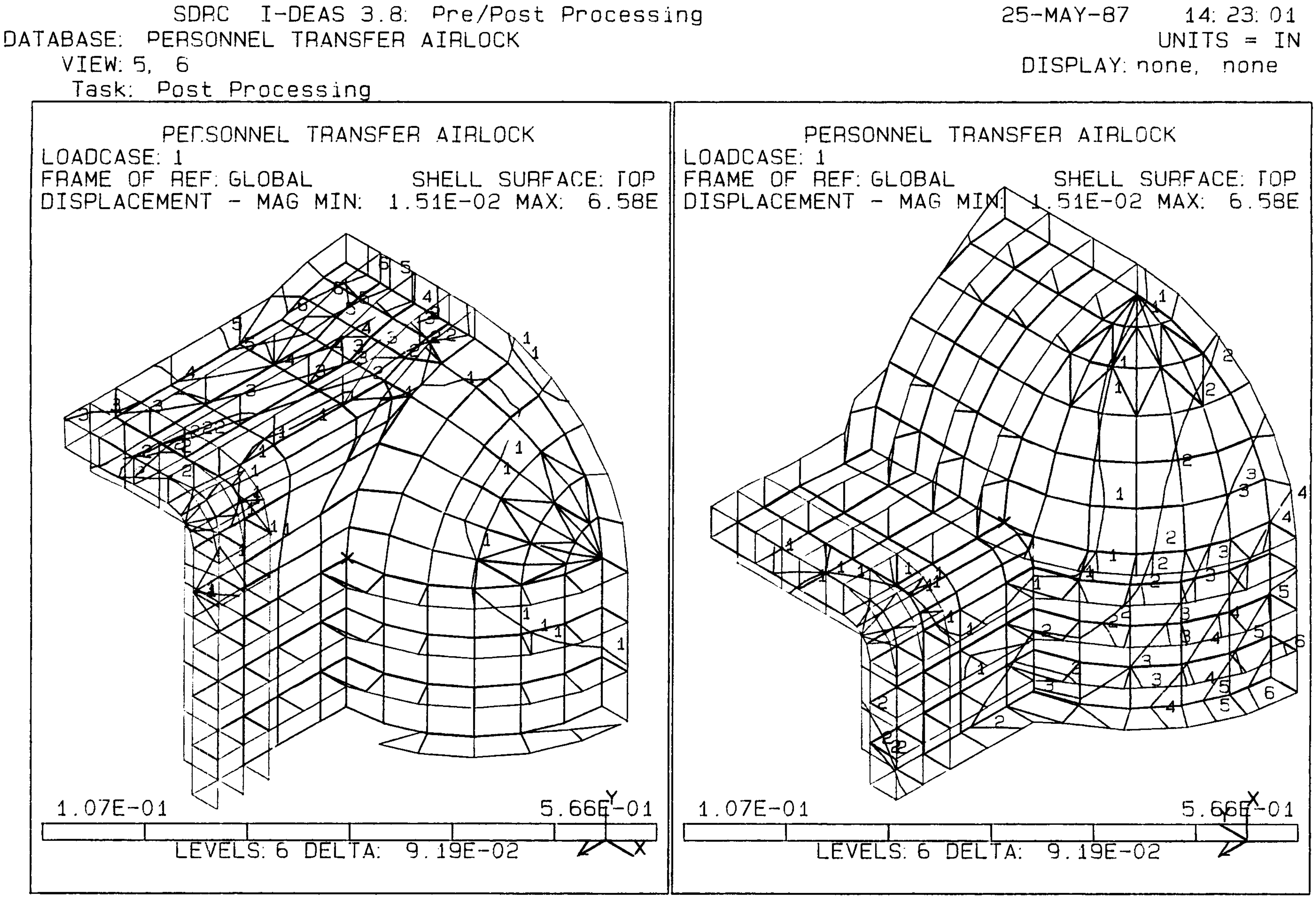

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: PERSONNEL TRANSFER AIRLOCK
VIEW: 5, 6
Task: Post Processing
25-MAY-87 14:23:01
UNITS = IN
DISPLAY: none, none
PERSONNEL TRANSFER AIRLOCK
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
DISPLACEMENT - MAG MIN: 1.51E-02 MAX: 6.58E
1.07E-01
5.66E-01
LEVELS: 6 DELTA: 9.19E-02
PERSONNEL TRANSFER AIRLOCK
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
DISPLACEMENT - MAG MIN: 1.51E-02 MAX: 6.58E
1.07E-01
5.66E-01
LEVELS: 6 DELTA: 9.19E-02

Figure 20

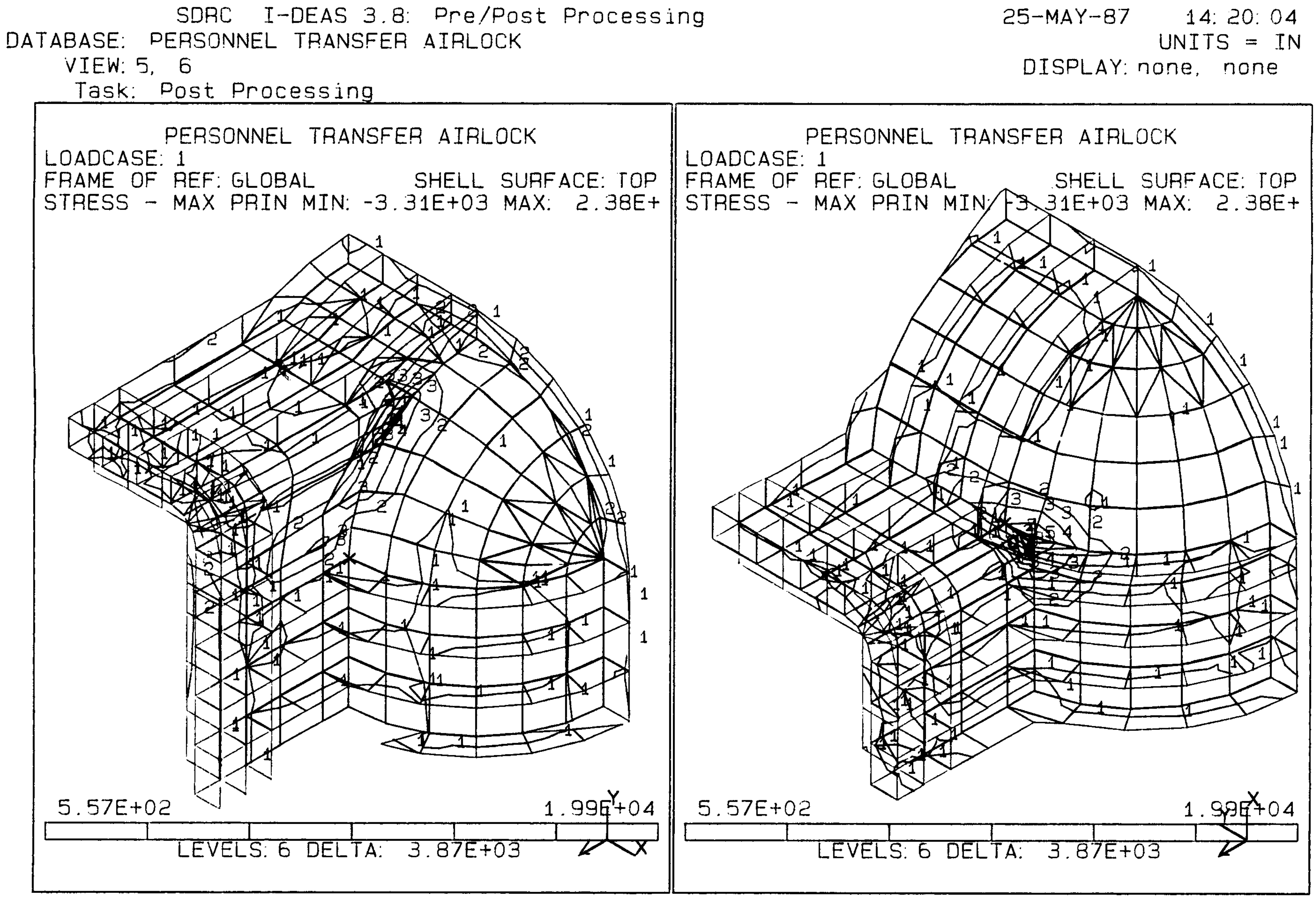

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: PERSONNEL TRANSFER AIRLOCK
VIEW: 5, 6
Task: Post Processing
25-MAY-87 14:20:04
UNITS = IN
DISPLAY: none, none
PERSONNEL TRANSFER AIRLOCK
LOADCASE: 1
FRAME OF REF: GLOBAL SHELL SURFACE: TOP
STRESS - MAX PRIN MIN: -3.31E+03 MAX: 2.38E+
5.57E+02
1.99E+04
LEVELS: 6 DELTA: 3.87E+03
PERSONNEL TRANSFER AIRLOCK
LOADCASE: 1
FRAME OF REF: GLOBAL SHELL SURFACE: TOP
STRESS - MAX PRIN MIN: -3.31E+03 MAX: 2.38E+
5.57E+02
1.99E+04
LEVELS: 6 DELTA: 3.87E+03

Figure 21

PUMP PERFORMANCE

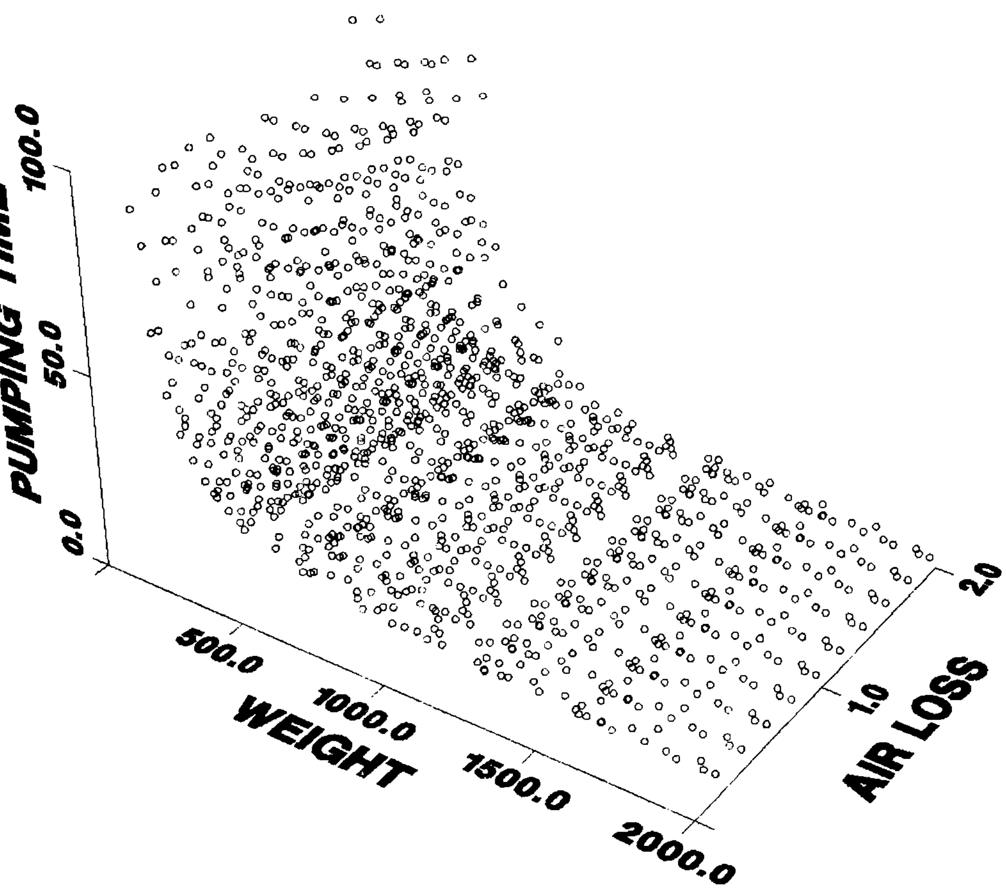


Figure 22

APPENDICES

APPENDIX 1 STRUCTURAL ANALYSIS

APPENDIX 1 STRUCTURAL ANALYSIS

Referenced figures are at the end of this Appendix.

Hatch Door - Thick Plate

The first concept to be analyzed for a possible design of the hatch door was the thick plate. A one-half inch thick plate of the above mentioned hatch door dimensions was generated and analyzed under two load cases. The first case was that of internal pressure causing the hatch to seat on the seal in a normal manner. The second load case was one in which reverse pressure was applied to the hatch door. This second case analysis was performed in order to determine if the deflection associated with this reverse pressure would break the preloaded seal, thus causing the airlock to leak.

The applied pressure in the first case was 30 psi, (See Figure A1-1) which represented a safety factor of 2 under the assumption that lunar module pressure would be one atmosphere, or 14.7 psi. Solution of the model yielded a maximum displacement of 6.89 inches occurring at the center of the hatch door. (See Figure A1-2) A maximum principal stress of 2.58E+5 psi occurred at the center of the door. (See Figure A1-3) The solution also yielded reactions at the restrained nodes which are interpreted as the force exerted on the seal by the hatch door. The maximum reaction force had a magnitude of 1.44E+4 lbf which occurred along both vertical edges. (See Figure A1-4)

The reverse pressure, 30 psi, would be the pressure present on the hatch door in the event that the airlock contained pressure while the lunar base module was evacuated. The hatch door was restrained at six nodes to represent a locking mechanism on each edge of the door. (See Figure A1-5) The maximum deflection of 5.56 inches occurred at the center of the door. (See Figure A1-6) Of more concern was the deflection of the nodes around which the seal would contact. The maximum deflection along the edge of the door was 4.77 inches. (See Figure A1-6) This deflection indicated that the door would leak in the reverse loading case indicating the need for a new design. Maximum stresses on the order of 1.66E+5 occurred again at the center of the door. (See Figure A1-7) Analysis of the reaction forces indicated that maximum magnitudes occurred at the location of the locking mechanism on each side. The solution suggested that the locking mechanism would have to support a maximum load of 3.74E+4 lbf in the reverse load case. (See Figure A1-8)

The conclusion of this first analysis was that a new design would be needed in order to minimize the deflections associated with the thick plate concept. The decision was then made to use a composite type design in order to increase rigidity and minimize weight, resulting in the final hatch door design discussed in the body of this report.

Airlock Module Skin

In this preliminary analysis the skin was the only object examined. Because of symmetry only 1/4 of the entire skin was analyzed. (See Figure A1-9) The load case applied to this model was that of 15 psi of internal pressure. From the displacement solution it was found that maximum deflections of 44.9 inches occurred on the extension walls and cylindrical sides and top of the skin. (See Figure A1-10) Examination of the principal stresses showed the highest stress to be in the spherical caps located on the airlock module corners. The magnitude of the maximum stress was 1.19E+5. (See Figure A1-11)

SDRC I-DEAS 3.8: Pre/Post Processing 16-APR-87 13:38:47
DATABASE: HATCH DOOR FOR AIRLOCK MODULE UNITS = IN
VIEW: No stored VIEW DISPLAY: No stored OPTION
Task: Analysis Cases

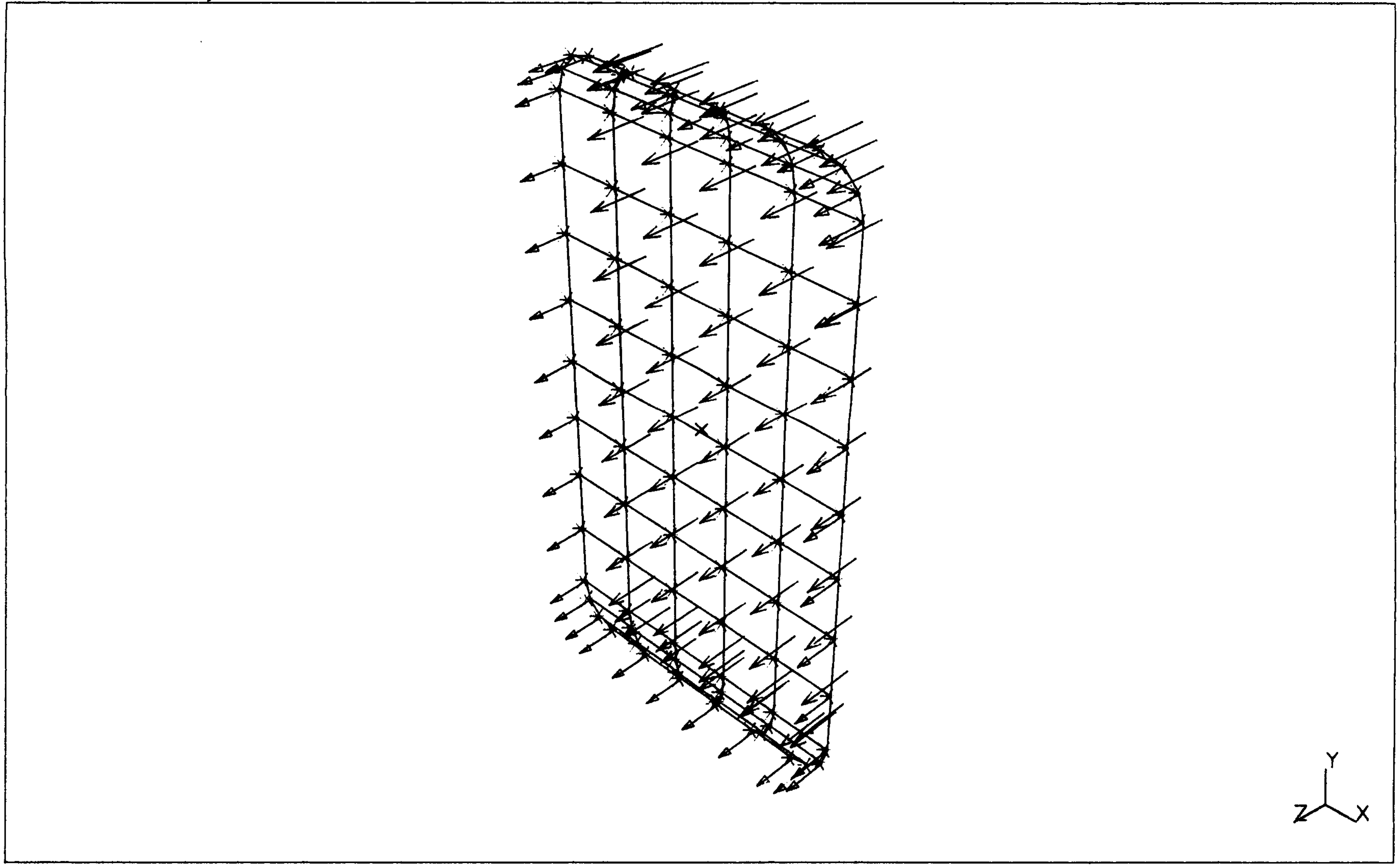


Figure A1-1

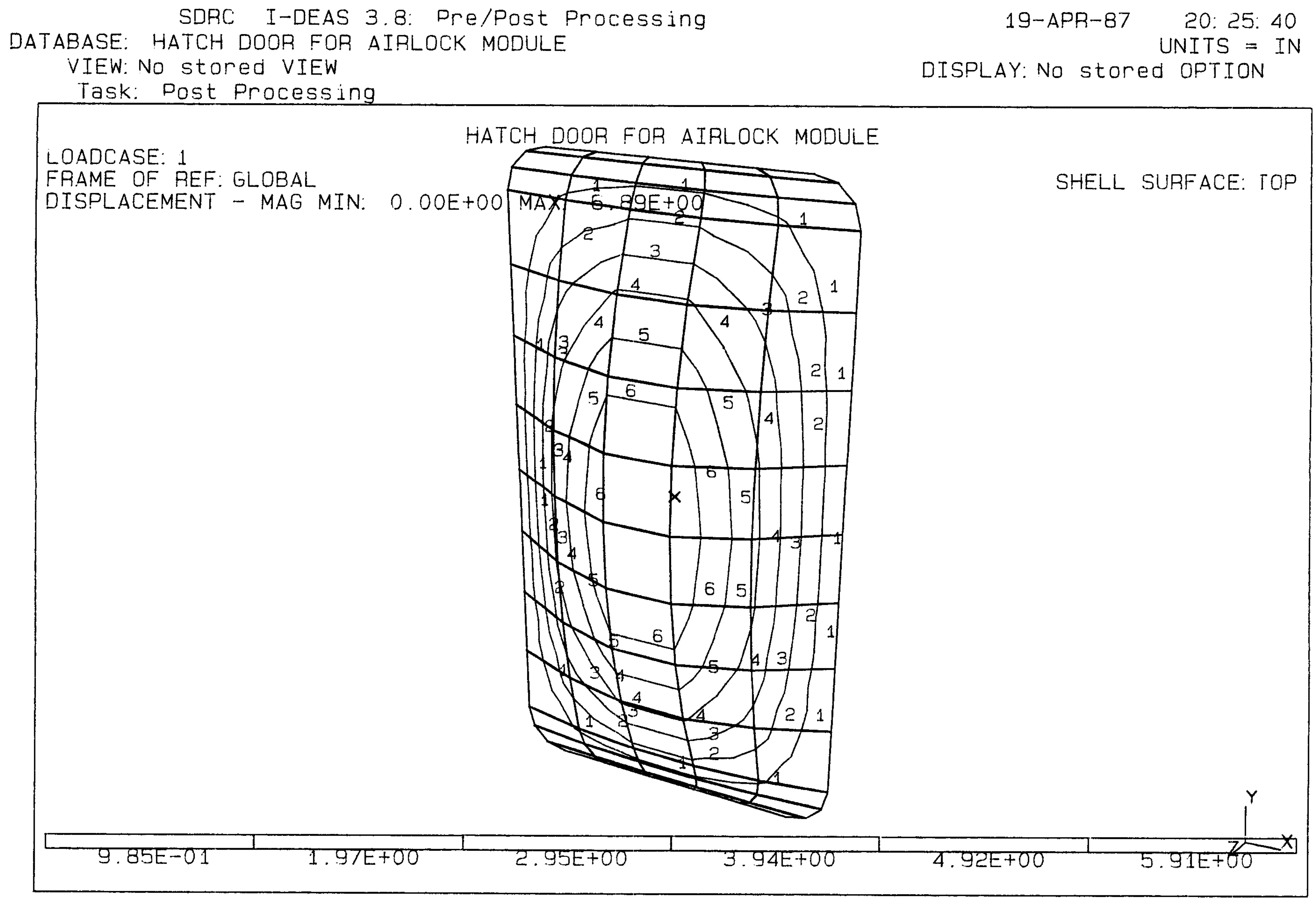

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing
19-APR-87 20: 25: 40
UNITS = IN
DISPLAY: No stored OPTION
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 1
FRAME OF REF: GLOBAL
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 6.89E+00
SHELL SURFACE: TOP
9.85E-01
1.97E+00
2.95E+00
3.94E+00
4.92E+00
5.91E+00
Y
X
Z

Figure A1.2

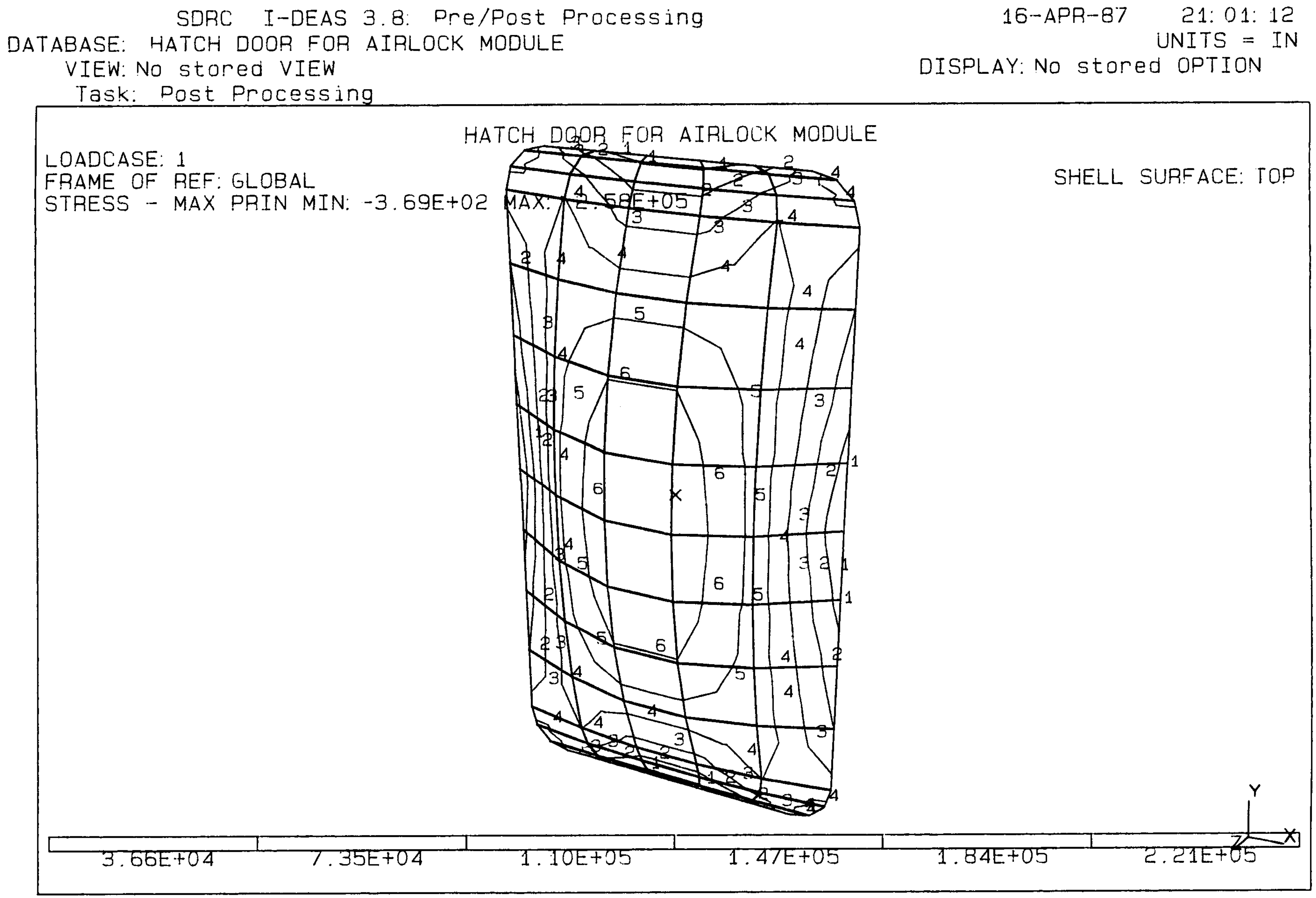

SDRC I-DEAS 3.8: Pre/Post Processing
16-APR-87 21:01:12
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
UNITS = IN
VIEW: No stored VIEW
DISPLAY: No stored OPTION
Task: Post Processing
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 1
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -3.69E+02 MAX: 2.58E+05
SHELL SURFACE: TOP
3.66E+04
7.35E+04
1.10E+05
1.47E+05
1.84E+05
2.21E+05
Y
X
Z

Figure A1-3

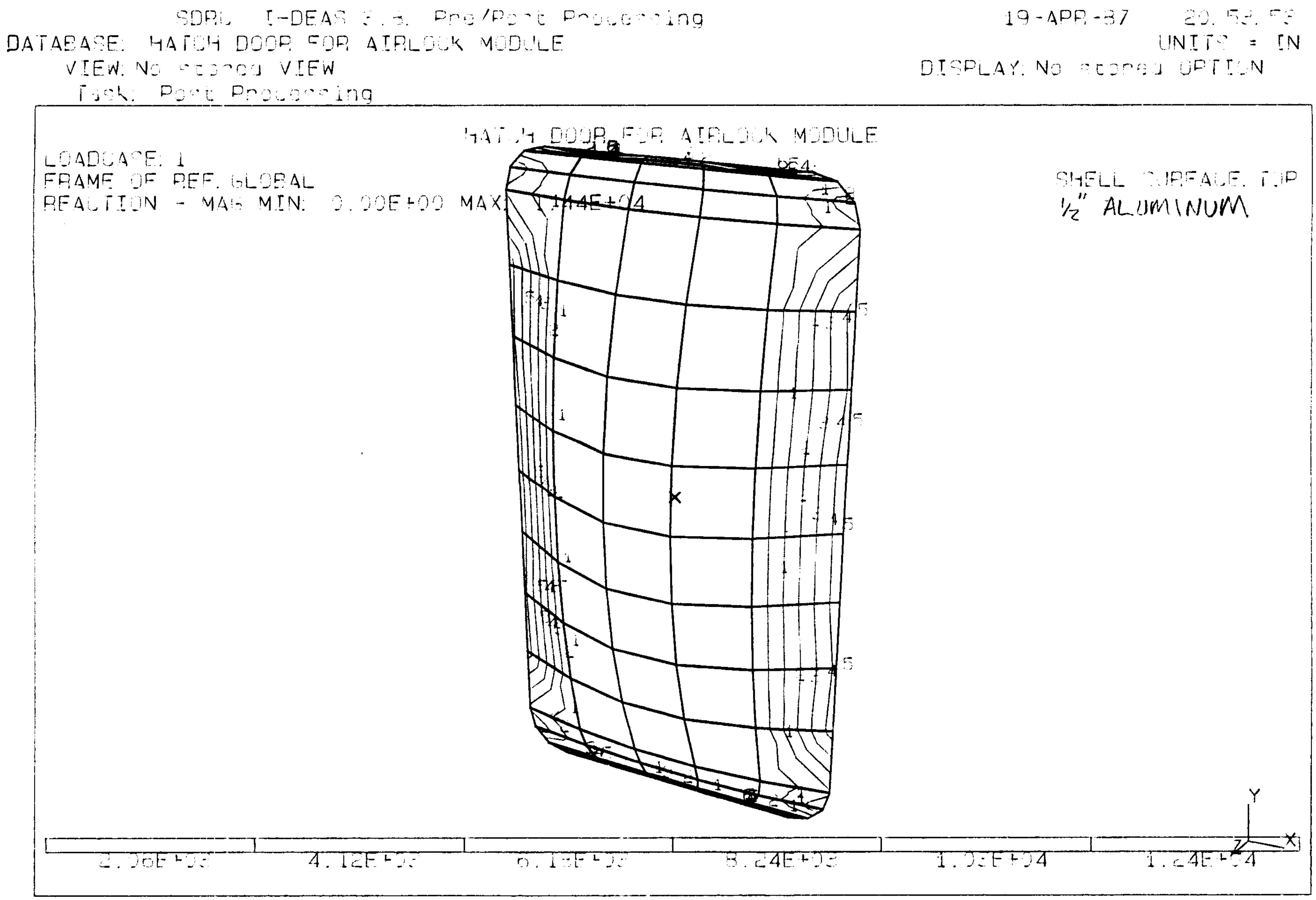

SDRL I-DEAS Pre/Post Processing
19-APR-87
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
UNITS = IN
VIEW: No stored VIEW
DISPLAY: No stored OPTION
Task: Post Processing
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 1
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 1.44E+04
SHELL SURFACE: TOP
1/2" ALUMINUM
4.12E+03
8.24E+03
1.24E+04
Y
X
Z

Figure A1-4

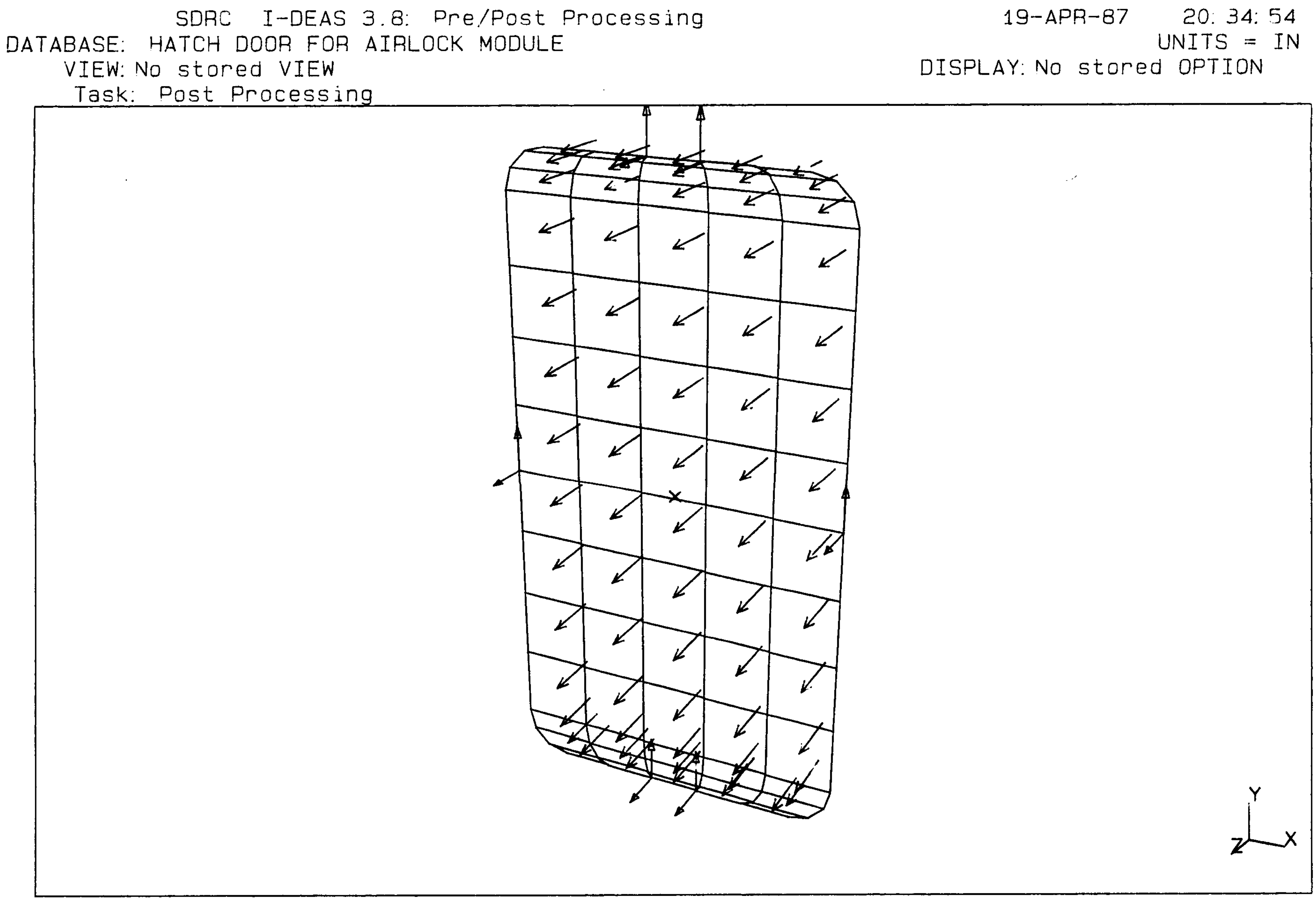

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing
19-APR-87 20:34:54
UNITS = IN
DISPLAY: No stored OPTION
Y
Z
X

Figure A1-5

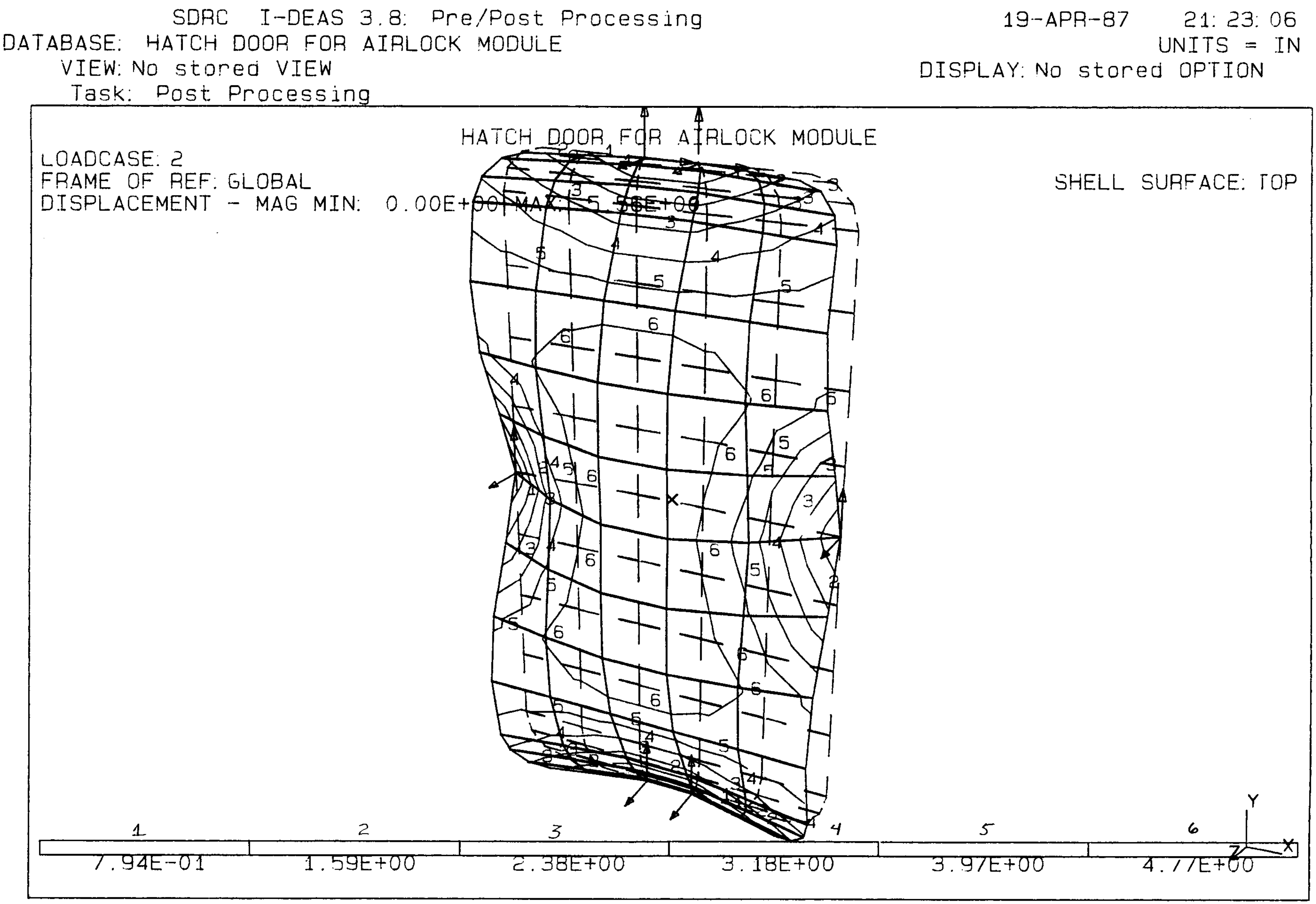

SDRC I-DEAS 3.8: Pre/Post Processing
19-APR-87 21:23:06
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
UNITS = IN
VIEW: No stored VIEW
DISPLAY: No stored OPTION
Task: Post Processing
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 2
FRAME OF REF: GLOBAL
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 5.56E+00
SHELL SURFACE: TOP
1 7.94E-01
2 1.59E+00
3 2.38E+00
4 3.18E+00
5 3.97E+00
6 4.77E+00
Y
X
Z

Figure A1-6

SDRC I-DEAS 3.8: Pre/Post Processing 19-APR-87 21: 27: 16
DATABASE: HATCH DOOR FOR AIRLOCK MODULE UNITS = IN
VIEW: No stored VIEW DISPLAY: No stored OPTION
Task: Post Processing

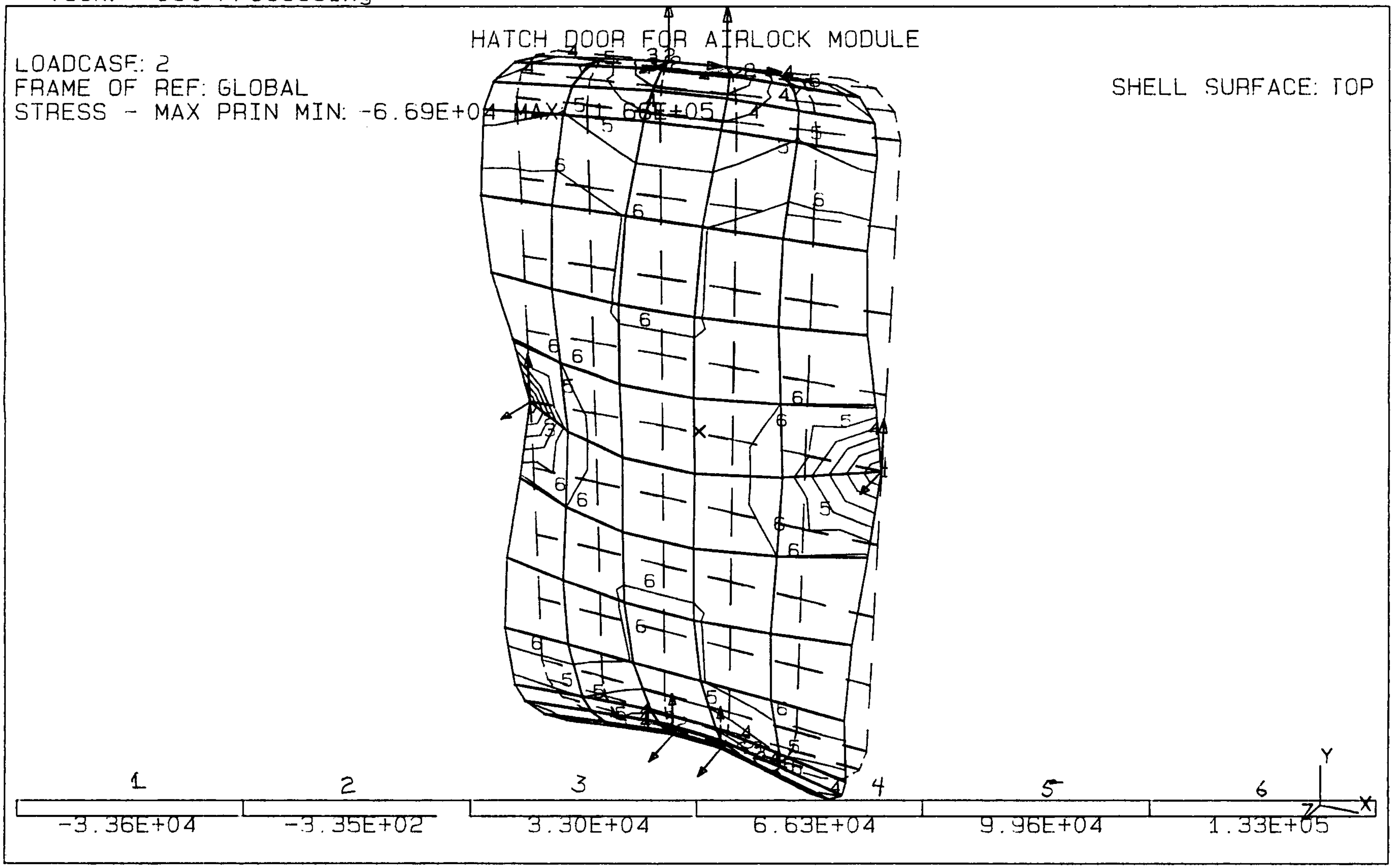


Figure A1-7

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing

19-APR-87 21:26:06
UNITS = IN
DISPLAY: No stored OPTION

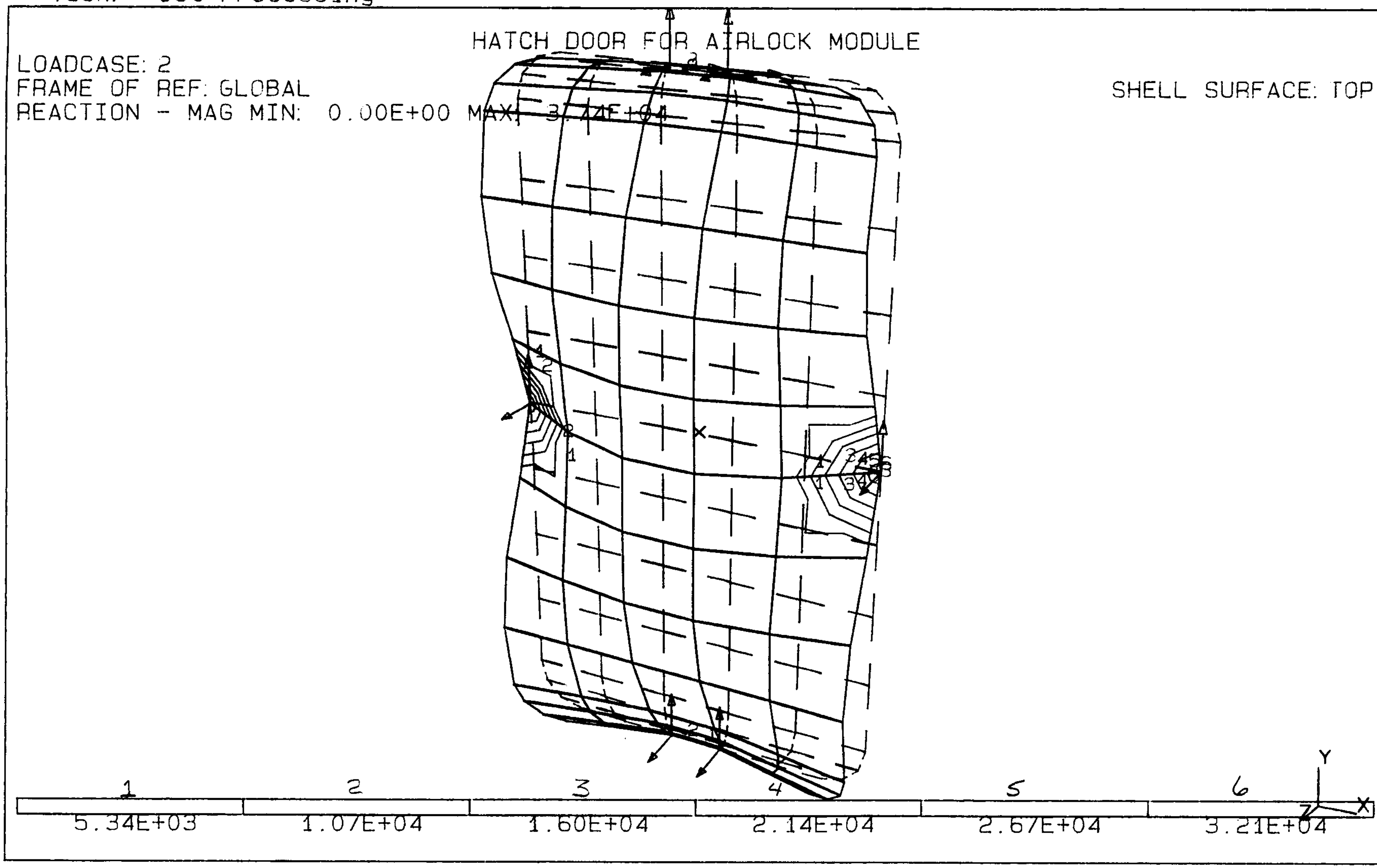


Figure A1-8

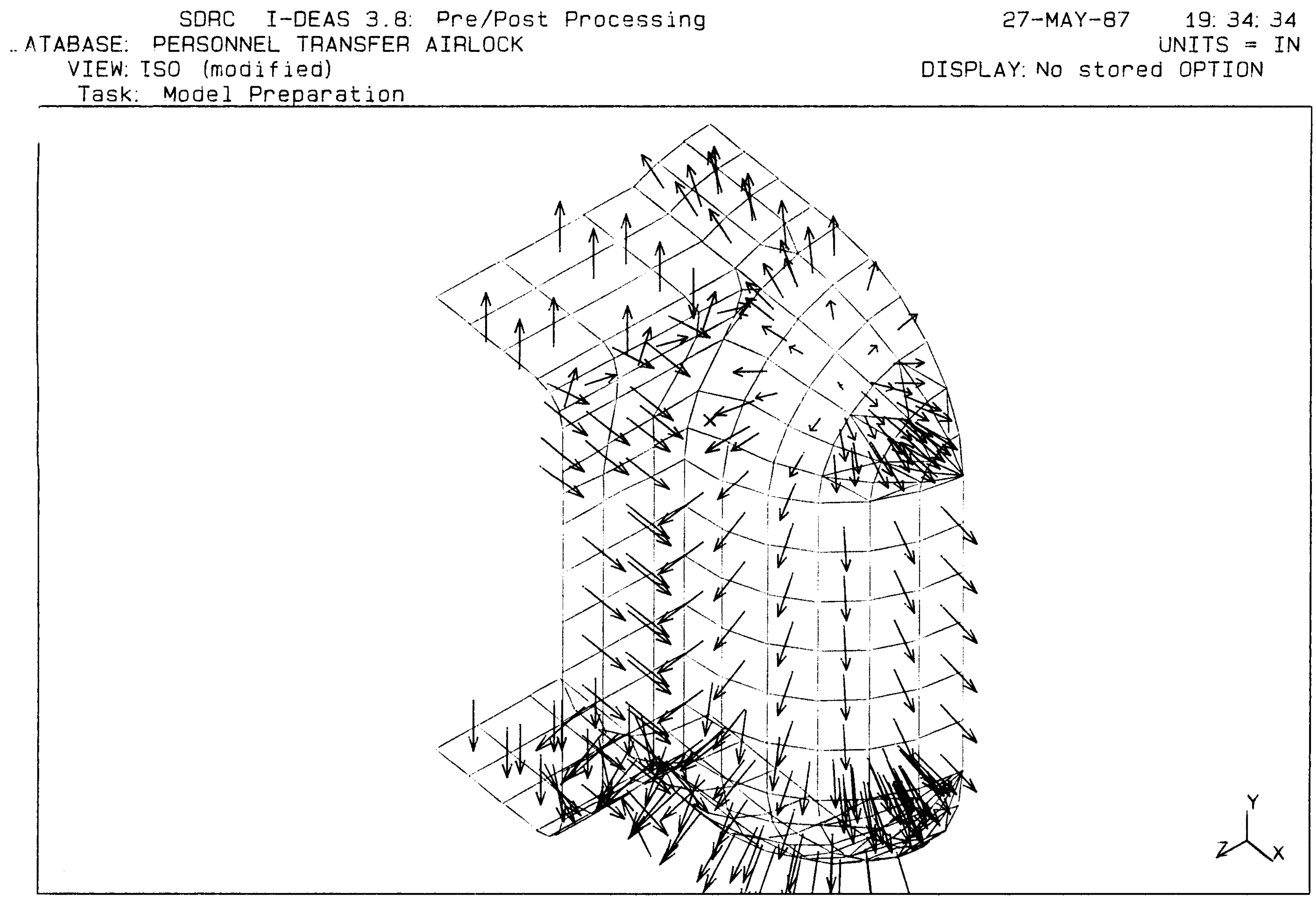

SDRC I-DEAS 3.8: Pre/Post Processing
27-MAY-87 19:34:34
..ATABASE: PERSONNEL TRANSFER AIRLOCK
UNITS = IN
VIEW: ISO (modified)
DISPLAY: No stored OPTION
Task: Model Preparation
Y
Z
X

Figure A1-9

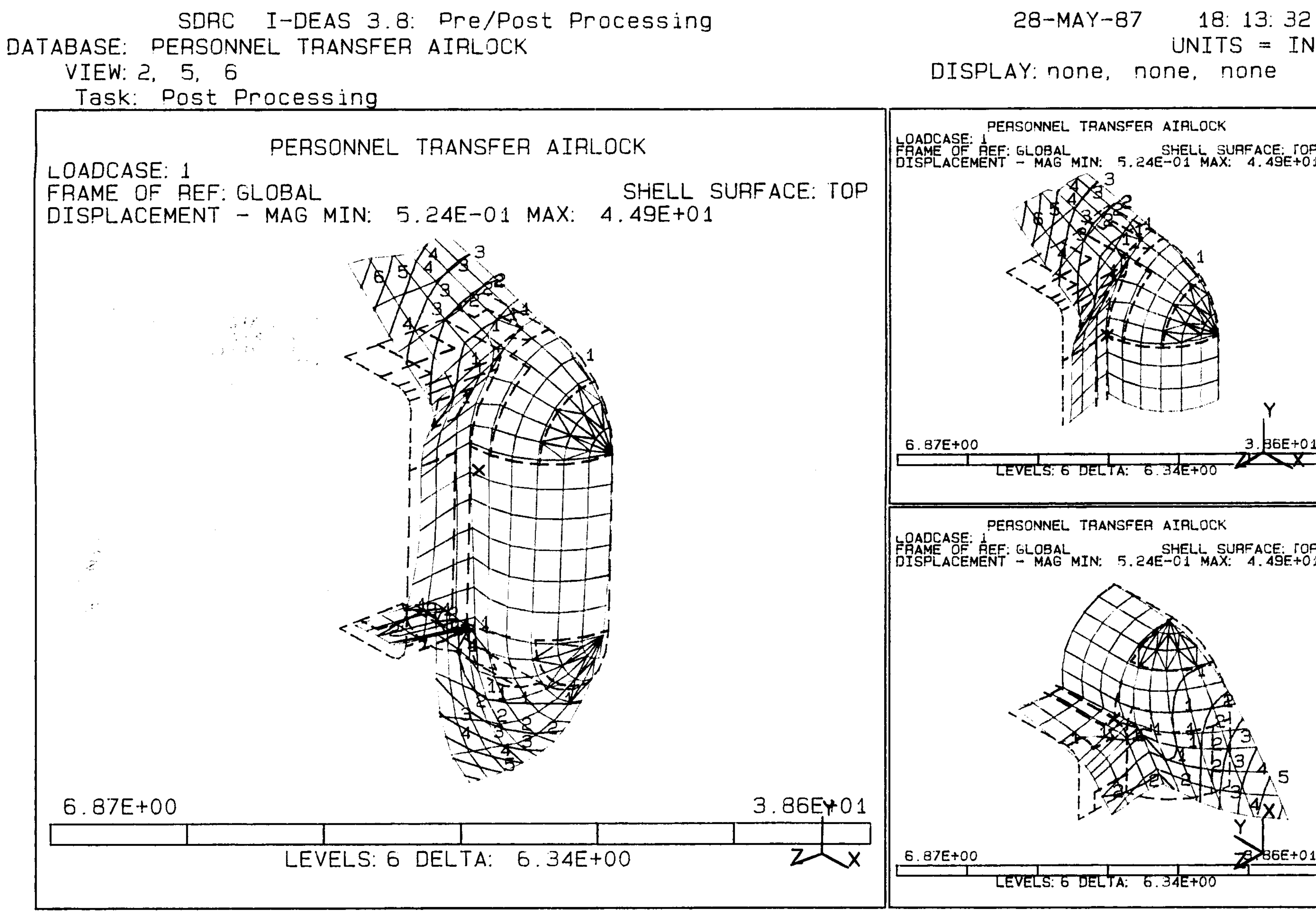

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: PERSONNEL TRANSFER AIRLOCK
VIEW: 2, 5, 6
Task: Post Processing
28-MAY-87 18:13:32
UNITS = IN
DISPLAY: none, none, none
PERSONNEL TRANSFER AIRLOCK
LOADCASE: 1
FRAME OF REF: GLOBAL
SHELL SURFACE: TOP
DISPLACEMENT - MAG MIN: 5.24E-01 MAX: 4.49E+01
6.87E+00
3.86E+01
LEVELS: 6 DELTA: 6.34E+00

Figure A1-10

SDRC I-DEAS 3.8: Pre/Post Processing 28-MAY-87 18:18:50
DATABASE: PERSONNEL TRANSFER AIRLOCK UNITS = IN
VIEW: 2, 5, 6 DISPLAY: none, none, none
Task: Post Processing

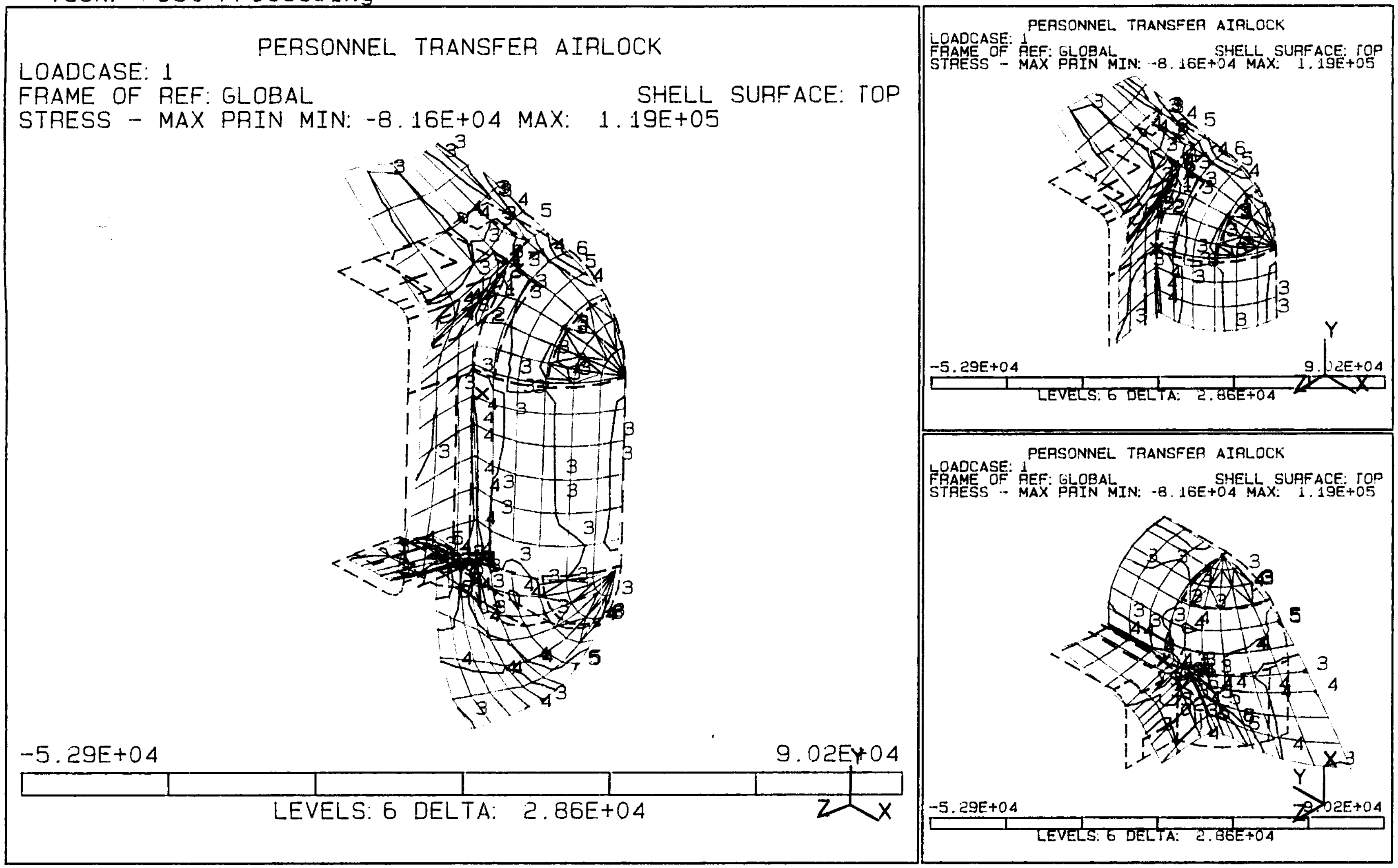


Figure A1-11

APPENDIX 2 VACUUM SYSTEM DESIGN ANALYSIS

```
C    TEST
      PROGRAM PUMP(INPUT,OUTPUT,PUMPDAT,PUMPIN,PUMPOUT,TAPE5=INPUT,
     C  TAPE6=OUTPUT,TAPE7=PUMPDAT,TAPE8=PUMPIN,TAPE9=PUMPOUT)
      CHARACTER PID(50)*8
      INTEGER N,K,I,NPOINTS(50),L,J,JS,JF,NUMPUMP
      REAL WEIGHT(50),P1(35,50),S1(35,50),PS1,PF1,P(35),S(35)
      REAL PF,PS,SF,SS,M,V,TIMESUM,TIME,DP,PDUM,SUM
      REAL PTORR,FNA,LOSS
      READ (7,*) N
      DO 10 K = 1,N
         READ (7,5) PID(K)
  5      FORMAT (A8)
         READ (7,*) WEIGHT(K)
         I = 1
 30      READ (7,*) PTORR,S1(I,K)
         P1(I,K) = PTORR * 1.332895
         IF (P1(I,K) .EQ. 0) GOTO 20
         I = I + 1
         GOTO 30
 20      NPOINTS(K) = I - 1
 10   CONTINUE
      READ (5,*) V
      PS1 = 700
      DO 700 K = 1,N
      I = NPOINTS(K)
      DO 800 NUMPUMP = 1,5
      PRINT*
      DO 800 PF1 = 1,1
      DO 40 L = 1,I
         P(L) = P1(L,K)
         S(L) = S1(L,K)
 40   CONTINUE
      IF (PS1 .GT. P(1) .OR. PF1 .LT. P(I)) THEN
         WRITE (6,15)
 15      FORMAT (' PUMP DATA INSUFFICIENT')
         GOTO 700
      ENDIF
      DO 50 J = 2,I
      IF (PS1 .GT. P(J) .AND. PS1 .LE. P(J-1)) JS = J - 1
      IF (PF1 .GE. P(J) .AND. PF1 .LT. P(J-1)) JF = J
 50   CONTINUE
      IF (JS .EQ. 0 .AND. JF .EQ. 0) WRITE (9,60)
 60   FORMAT ('NO DATA')
      P(JS) = PS1
      P(JF) = PF1
      S(JS) = S(JS+1)+((S(JS)-S(JS+1))/(P(JS)-P(JS+1)))*(PS1-P(JS+1))
      S(JF) = S(JF)+((S(JF-1)-S(JF))/(P(JF-1)-P(JF)))*(PF1-P(JF))
      TIMESUM = 0
      DO 70 J = JF,JS+1,-1
         PF = P(J)
         PS = P(J-1)
         SF = S(J)*NUMPUMP
         SS = S(J-1)*NUMPUMP
         M = (SS-SF)/(PS-PF)
         DP = (PS-PF)/100
         SUM = 0
         DO 100 PDUM = PS,PF+DP,-DP
            FNA = DP / (M*(PDUM-DP/2)**2+(SF-M*PF)*(PDUM-DP/2))
            SUM = SUM + FNA
100      CONTINUE
```

```
            TIME = SUM * V
            TIMESUM = TIMESUM + TIME
   70 CONTINUE
      LOSS = PF1 * V * 7.39888E-5
      WRITE (6,650) PID(K),WEIGHT(K),NUMPUMP,PF1,TIMESUM,LOSS,
     C   WEIGHT1,TIMESUM/LOSS,TIMSUM/WEIGHT1,LOSS/WEIGHT1
  650 FORMAT(5X,A8,F8.0,I8,F8.0,F12.2,E16.2,F10.0,F12.1,F15.4,E15.2)
      WRITE(9,850) WEIGHT1,TIMESUM,LOSS
  850 FORMAT (2X,F7.0,F7.2,E11.4)
  800 CONTINUE
  700 CONTINUE
  600 STOP
      END
```

APPENDIX 3 COST AND VOLUME ANALYSIS

APPENDIX 3 COST AND VOLUME ANALYSIS

COST

The following weights and costs are computed using the following constants:

For Aluminum Alloy 5052: 5.28 lb/ft^2
$1.35/lb

For Aluminum Alloy 6063: 7.03 lb/ft^2
$1.49/lb

	Area ft^2	Weight lbs	Cost $
AIRLOCK MODULE			
Skin, 5052			
2 cylinders: 2(2)(π)(2.5)(5)	157.08		
sphere: 4(π)(2.5^2)	78.54		
2 rectangles: 4(2)(5)	40.00		
4(2)(7.67)	61.34		
Total	336.97		
		1779.13	
			2402
Ribs, 6063			
28 ribs: 2(.5)(.042)	28.00		
14 ribs: 7.854(.5)(.042)	54.98		
1 rib: 35.71(.5)(.042)	17.86		
14 ribs: 6.02(.5)(.042)	42.14		
4 ribs: 7(.5).042)	14.00		
Total	156.98		
		1103.57	
			1644
TOTAL FOR AIRLOCK MODULE		2882.70	4046
HATCH MODULES WITH DOORS			
Skin, 5052			
2 cylinders: 4(π)(.5)(1)	6.28		
2 rectangles: 4(1)(6)	24.00		
4(1)(5)	20.00		
Total	50.28		
		265.48	
			359
Ribs, 6063			
2(42 ribs): 2(.5)	42.00		
2(3 ribs): ((2*6)+(2*5)+.5*π*2))	75.40		
Total	117.40		
		825.32	
			1230

3 Flanges, 6063			
rectangle: 3((2*6)+(2*5))	33.00		
circle: $3(\pi)(8/12)^2$	4.19		
Total	37.19		
		261.44	
			390
Door Ribs, 6063			
2(5 ribs): 2(7)(.5)	35.00		
2(4.5)(.5)	31.50		
Total	66.50		
		467.50	
			697
TOTAL FOR HATCH MODULE		1819.74	2676
GRATE FLOORING			
Grating, 6063			
circle: $\pi(2)^2$	12.60		
rectangle: 4(5)	20.00		
Total	32.60		
		229.00	
			342
Braces, 6063			
lip	3.75		
2 cross braces	2.19		
Total	5.94		
		41.76	
			62
TOTAL FOR GRATE FLOOR		270.76	404
HINGES			
2 hinges per door(2 doors)		80	4000
LOCKING MECHANISM			
1 lock per door(2 doors)		500	6000
HATCH DOOR SEAL			
1 seal per door(2 doors)		100	4000
Tooling cost			2000
EVACUATION SYSTEM			
3 pumps		900	3000
6 dust separators		90	4200
6 gate valves		240	1800
3 Secuvac valves		45	2700
hoses and conduit		20	100

CLEANING SYSTEM		
blower assembly	30	200
2 HEPA filters	100	600
pre-filters		5
hoses and ducts	50	100

TOTAL AIRLOCK SYSTEM WEIGHT:		7128 lbs
TOTAL MATERIAL COST:	$ 35,831	
ESTIMATED LABOR COST:	74,000	
TOTAL TRANSPORTATION COST: (at $22,000/lb)	156,820,400	
TOTAL COST	$156,930,231	

VOLUME

	Volume (ft^3)	
AIRLOCK MODULE		
square	125.00	
2 cylinders	301.91	
sphere	124.79	
2 flanges	173.34	
Total		725
HATCH MODULE		
2 rectangles		104
EVACUATION SYSTEM		
3 pumps	10.85	
3 motors	1.40	
Total		13
CLEANING SYSTEM		
HEPA filters, blower, motor		5
TOTAL VOLUME OF AIRLOCK SYSTEM		847

APPENDIX 4 ALTERNATIVE DESIGN CONCEPTS

APPENDIX 4-A AIRLOCK GEOMETRY

In the design of the airlock, one of the most important parameters considered was the time required to evacuate the volume of atmosphere inside the airlock to a vacuum, commonly called the pump time. Obviously, minimum pump time is the desired result. Pump time is strongly dependent on the amount of volume to be evacuated, which in turn is related to the amount of space in the airlock available for the astronauts. As will be discussed later, pump time is linearly related to volume. Therefore, the pump time required for a volume to accommodate four astronauts is approximately twice that required for a volume to accommodate two astronauts. In this regard, if four astronauts were to exit to the lunar surface, two evacuation cycles of a two person airlock would require the same time as one cycle of a four person airlock. However, if a four person airlock was employed, a longer evacuation period would be required even if only two astronauts were exiting the lunar base.

Several different geometric shapes were considered for the actual physical shape of the airlock. These included a rectangle, a cylinder, and a sphere. Upon examination of each of these geometries, several factors were noted. The rectangular configuration showed great promise for efficient use of space. (See graph at the end of this Appendix) However, as in the design of any type of pressure vessel, the rectangle lacked structural integrity because of stress considerations. The cylindrical design showed a significant improvement in this area. However, a potential problem occured when considering the hatch door design. The door could no longer be planar in design, which could lead to sealing problems. The spherical shape incorporated the best design for stress, but had the largest effective volume per person of the three geometries, resulting in an increase in pump time. In addition, the same potential sealing problems as encountered in the cylinder were also present.

Another consideration in the determination of geometry was design for stress. During the cycle of personnel transfer the airlock module will be pressurized to that of the module pressure level. The design of the airlock must take into consideration the stress caused by this process.

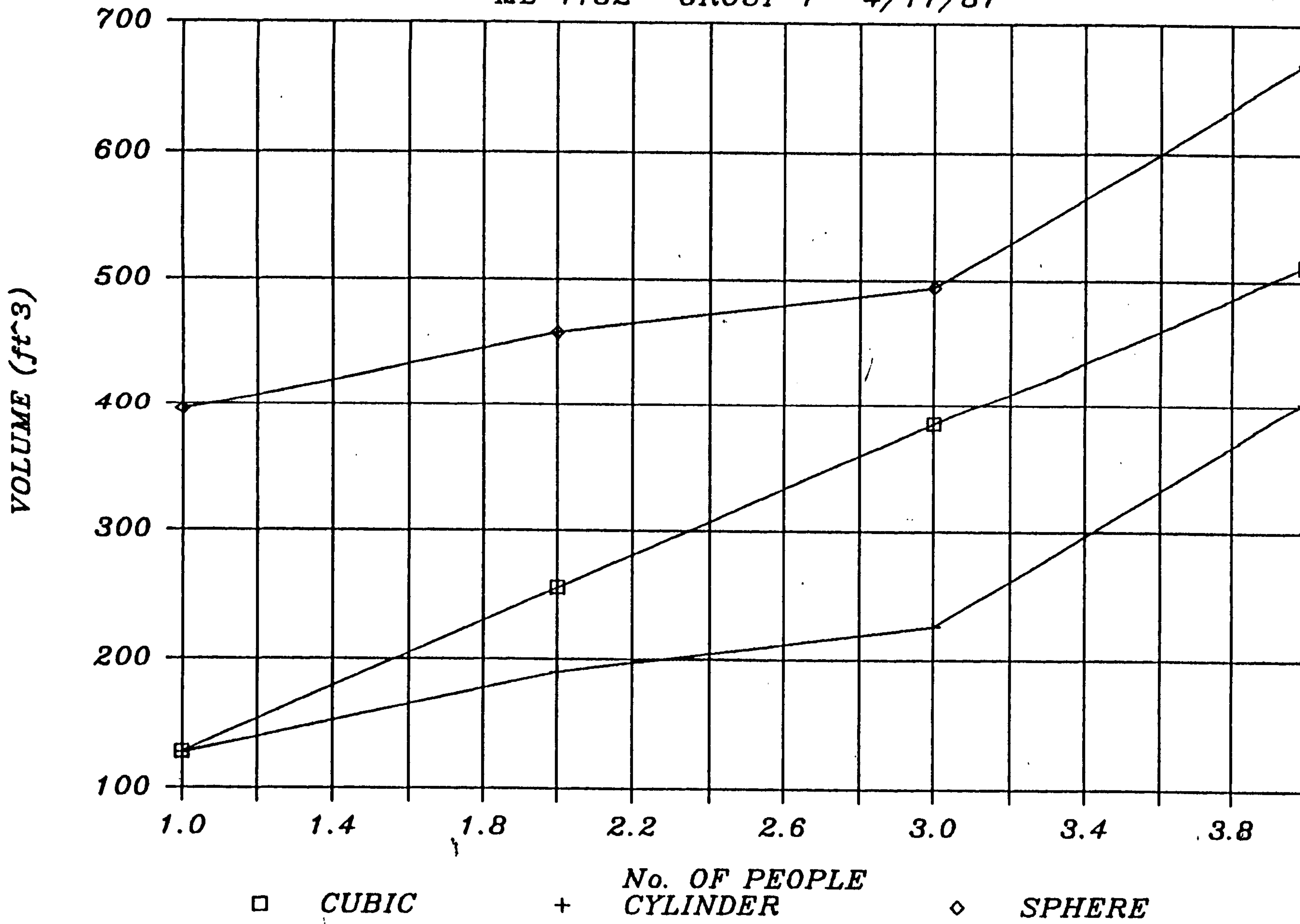
Obviously, of prime importance is the cost of transportation of the airlock system to the moon, which translates into dollars per pound. Therefore, it was desirable to have a lightweight material. However, it was also imperative that this material possess physical properties that would help to maintain the structural integrity of the unit.

During the analysis process, one of the first decisions to be made was that of the type of airlock system to design. Two possible alternatives were considered, an integrated design and a modular design. The integrated design incorporates a self-contained airlock unit that is independent of any surrounding attachments, i.e., module. Storage of the cleaning equipment would be below the floor and the evacuation system would be located in the module. However, the hatch door and associated mechanisms would be designed specifically for use in the airlock module. Several factors were noted concerning this design. First, a reduction in weight could be realized due to the fact that a smaller flange connecting the airlock to the base module could be utilized. However, for this smaller flange to be used, a sliding track door or a van type door must be used. If a hinged or swinging door were used, maneuverability within the airlock would be severely hampered. The door was chosen to swing into the airlock to take advantage of the pressure as a sealing force. The geometry of the door must allow adequate width for an astronaut to pass to and from the airlock. The height of the door must also allow for adequate headroom. A hatch door of this size coupled with the optimized effective volume of the airlock presents a problem. The problem is in having the door negotiate the radius of the end wall of the airlock module. If the airlock were lengthened to accommodate the door, the volume would be increased and, likewise, pump time.

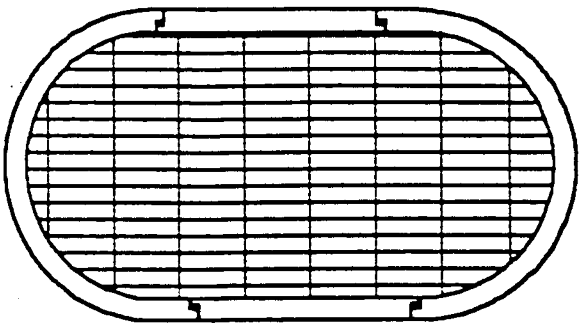
The modular design also has advantages and disadvantages. This design separates the system into an airlock module and separate individual hatch modules which would be connected to the airlock via bolted and sealed mating flanges. The disadvantage is increased weight due to the larger entrance area required. This larger entrance is necessary to provide an adequate area for maneuverability inside the airlock once the door is in the open position. The distinct advantage of this design is in the standardization for the modular hatch door unit. This unit would be made with mounting flanges on both sides of the door. Therefore, this unit could be used not only for the airlock, but wherever two modules need to be joined. A standardized unit, such as this, also has the advantage of maintainability. A replacement unit could be used while corrective action is taken on the faulty hatch module.

AIRLOCK VOLUME/VARIOUS GEOMETRIES

ME 4182 GROUP 1 4/17/87

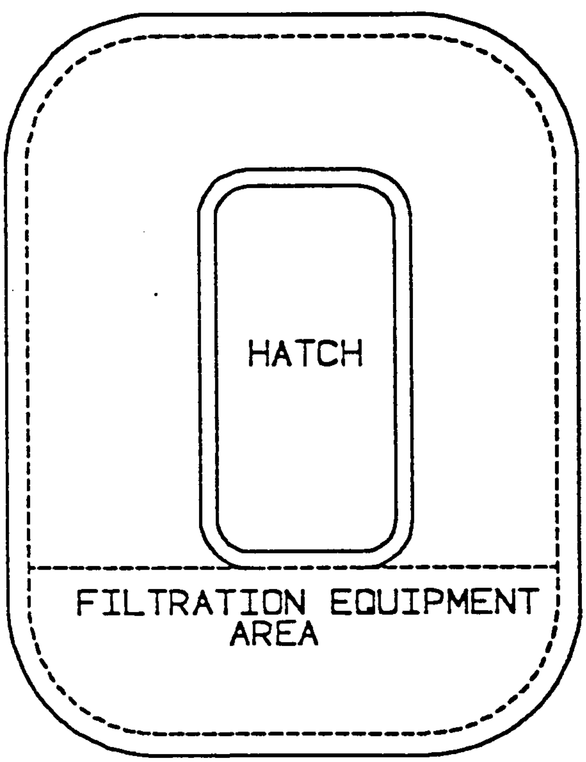


PERSONNEL TRANSFER AIRLOCK
GROUP I
TITLE: INTEGRATED AIRLOCK DESIGN
DATE DESIGNED: 4/26/87

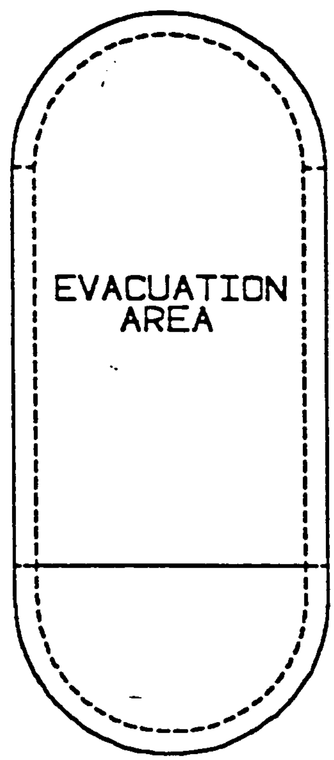


PLAN VIEW

NOTE: CROSS-HATCHED AREA INDICATES GRATING FLOOR

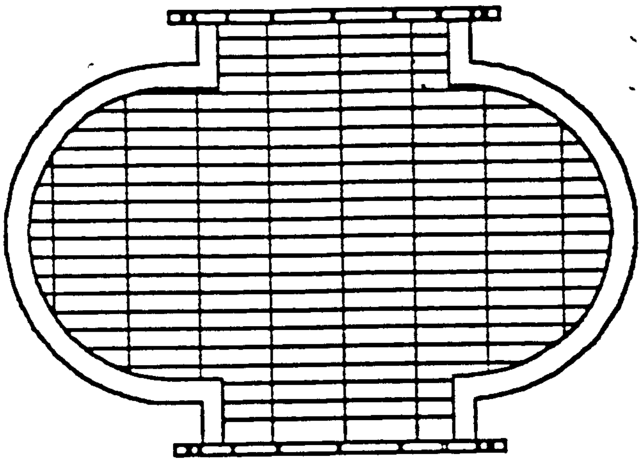


FRONT VIEW



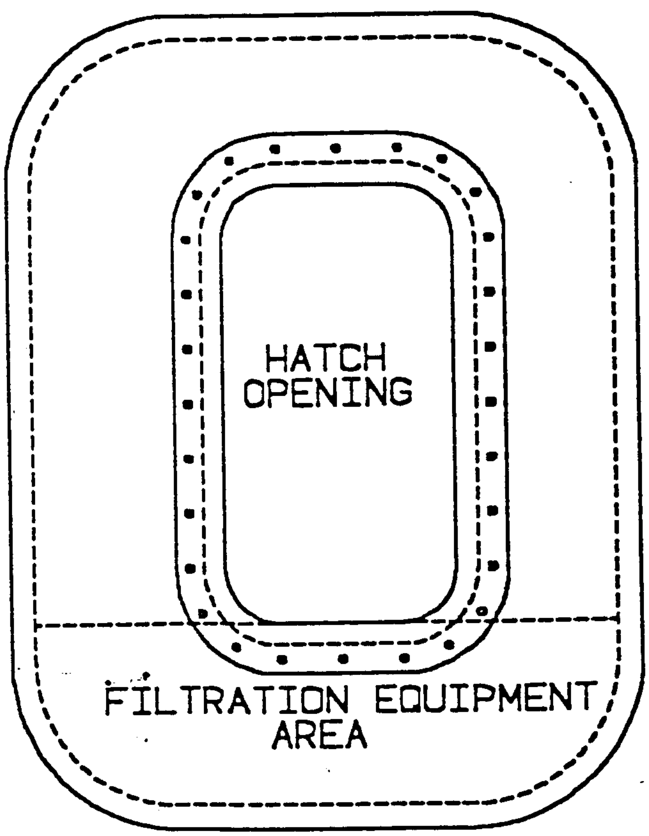
RIGHT VIEW

PERSONNEL TRANSFER AIRLOCK
GROUP I
TITLE: MODULAR AIRLOCK DESIGN
DATE DESIGNED: 4/26/87

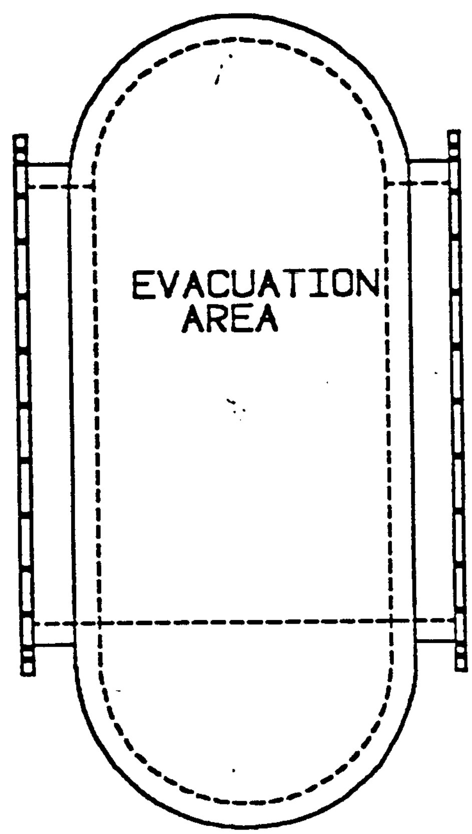


PLAN VIEW

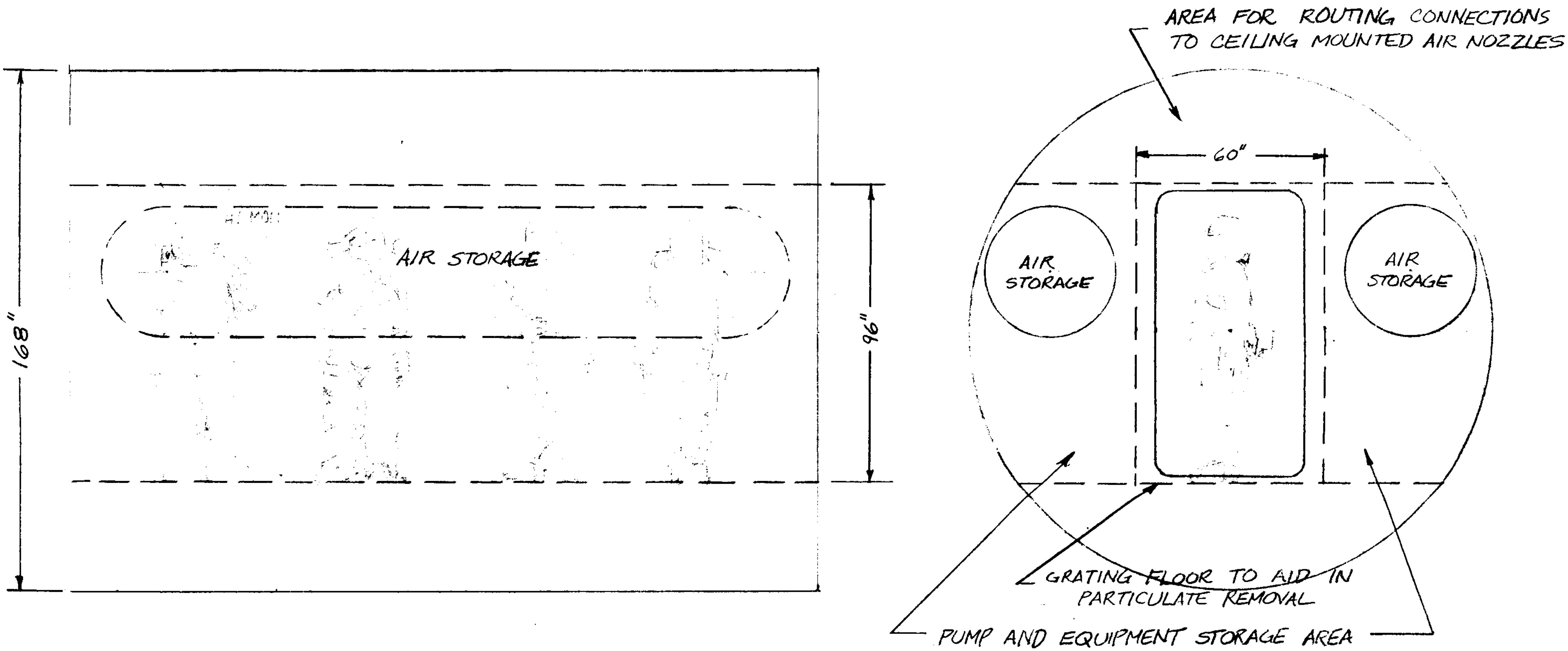
NOTE: CROSS-HATCHED AREA INDICATES GRATING FLOOR



FRONT VIEW

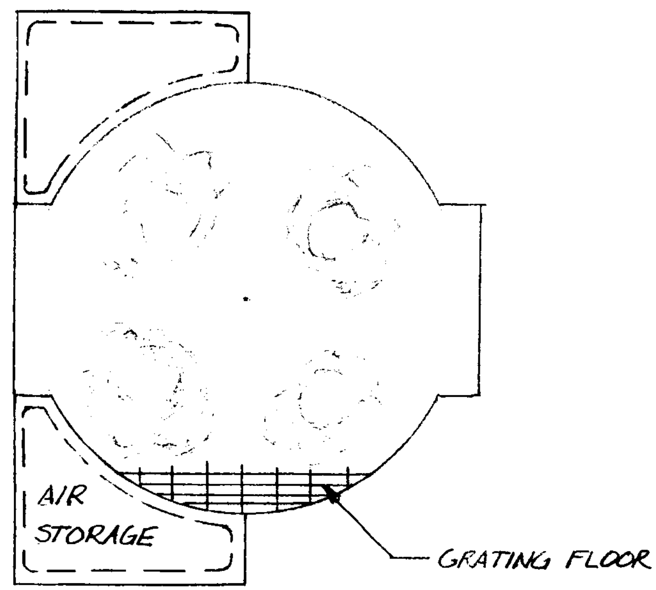


RIGHT VIEW

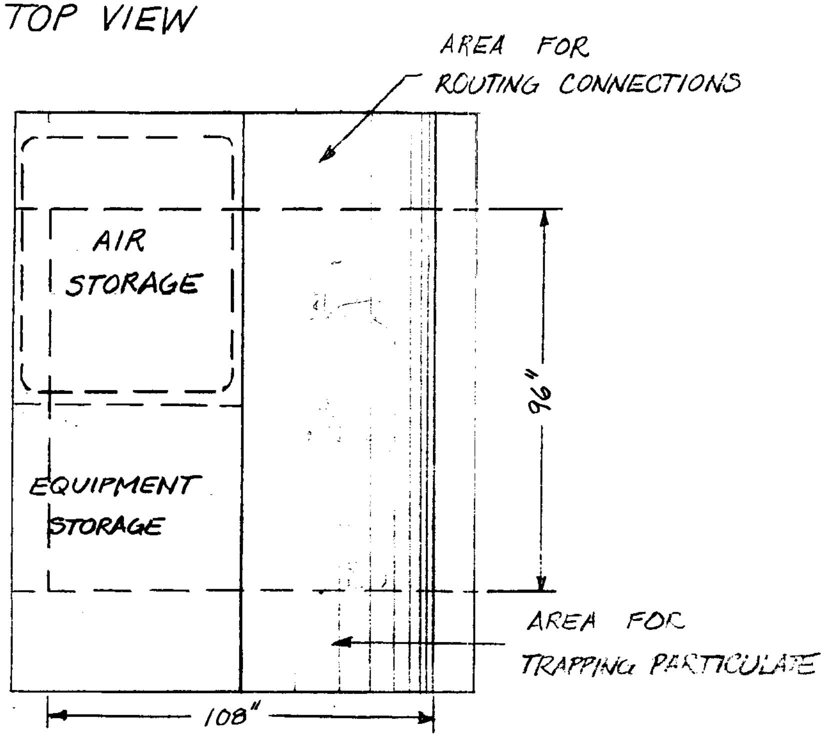


RECTANGULAR APPROACH

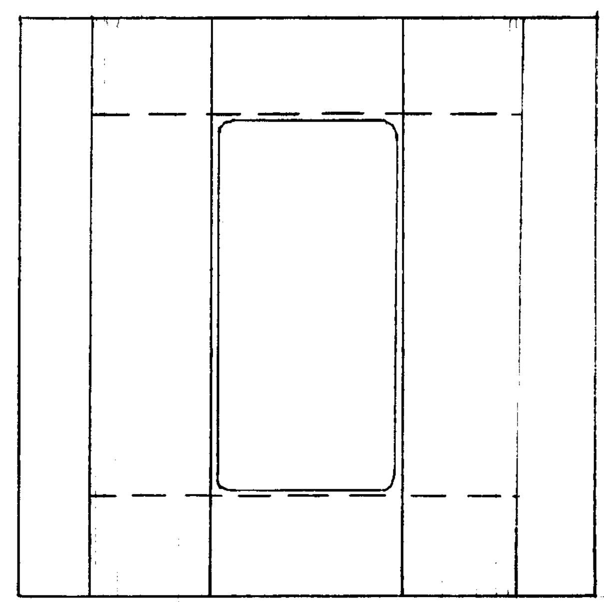
CYLINDRICAL APPROACH



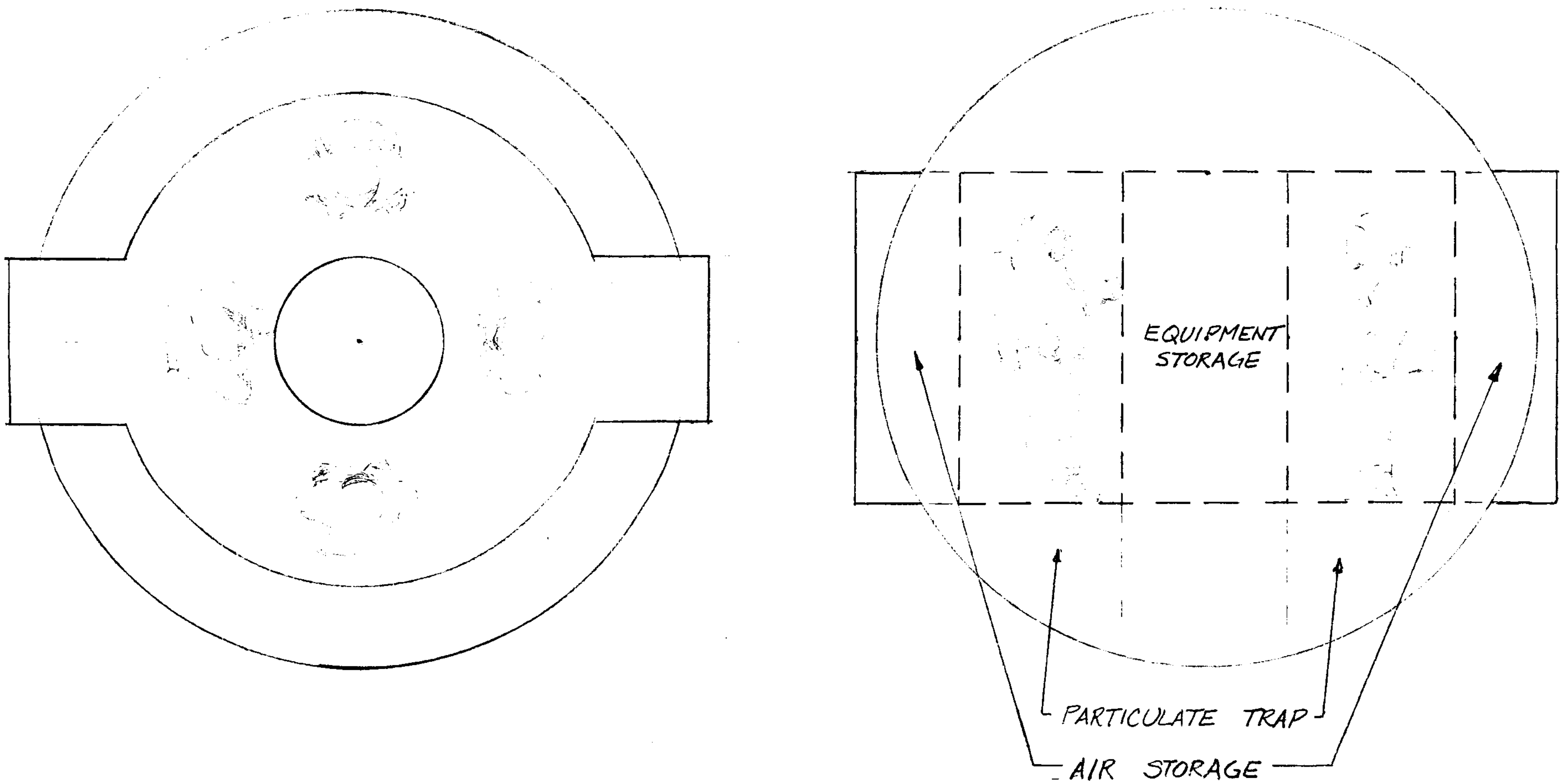
TOP VIEW



FRONT VIEW



RIGHT VIEW



SPHERICAL APPROACH

APPENDIX 4-B SEALS

In order to prevent the escape of air from the airlock when the hatch is closed, a seal must be placed between the hatch and the flange against which the hatch closes. The capabilities and requirements of this seal place significant constraints on the designs of the door, hinges, and the locking mechanism.

Since the seal and door designs are closely interrelated, the initial search for seal concepts was conducted with the idea of maintaining maximum flexibility in the door design. Since static seals severely limit the types of doors which may be used, the initial investigation focused upon the use of dynamic seals. A dynamic seal allows tangential relative motion between the sealing surface and the seal and, thus, does not require that the door maintain a constant position or orientation with respect to the seal. Although this condition is obviously desirable, several problems were identified with this type of seal design.

The most significant drawback of a dynamic seal is the fact that it must be designed with the assumption of a constant leakage rate. That is, the seal leaks slightly but continuously when in the "sealed" position. Since any leakage of air from the airlock module requires eventual replacement by an equivalent amount of air shipped from the earth, a continuous leakage is unacceptable for this design.

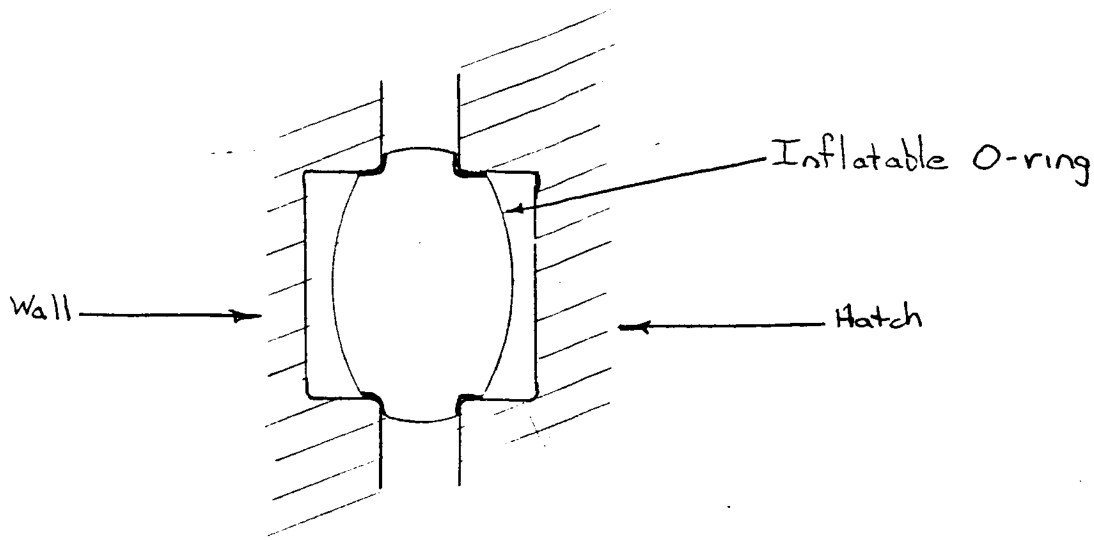
Several other problems exist with dynamic seals. The clearance between the seal and the sealing surface must be maintained within very close tolerances in order to provide proper sealing and minimize the friction between the two surfaces in relative motion. Because of the large temperature range which can be expected in the lunar environment, it would be impossible to maintain these clearances to within a reasonable limit. Relative motion between the seal and its sealing surface also greatly increases the amount of wear of the seal, necessitating more frequent maintenance than for a static seal. Maintenance is also more difficult, since a large part of the hatch mechanism would have to be disassembled in order to remove the seal.

Since the use of a dynamic seal presents several almost insurmountable difficulties, it was decided that a static seal would be the most suited to the airlock design constraints. Even though the design of a static seal is somewhat more simple than that of a dynamic seal, several critical factors must be considered. As mentioned previously, the lunar environment is subject to sudden extreme changes in temperature, and these must not compromise the integrity of the seal. Additionally, the seal leakage must be negligible when the hatch door is closed and locked, regardless of the direction of the pressure differential. Since reverse pressure, such as might occur during an emergency depressurization of the module, tends to deflect the door away from the seal, the seal must be reasonably forgiving of relatively large changes in the clearance between the two surfaces being sealed.

The use of a seal in a vacuum greatly increases the complexity of the design process by eliminating most of the materials commonly used in normal seals. These materials contain oils or other liquids which evaporate from the material when exposed to a vacuum, a condition known as outgassing. Thus, in addition to meeting all of the specifications mentioned previously, the seal material must also be able to survive exposure to vacuum conditions without significant loss of material.

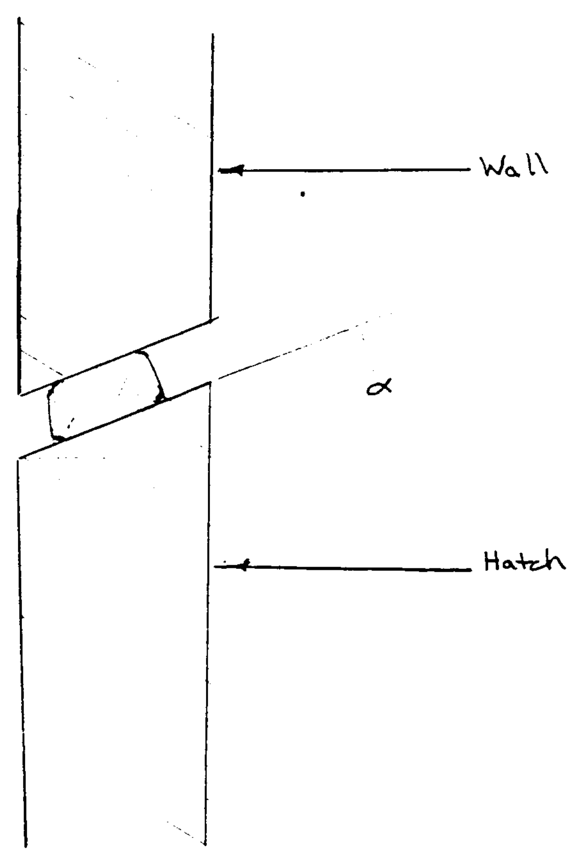
In addition to dynamic seals, various static seal geometries were discussed prior to making the final seal selection. The possible use of a standard o-ring seal was evaluated initially because of the simplicity of the seal and its ready availability. A "U" or "V" shaped seal was also discussed. This seal design was desirable because of its ability to form an excellent seal with the surfaces; however, it would not withstand the large compressive forces needed to guard against possible reverse pressure. An inflatable o-ring seal was also considered, but a lack of current technology and information precluded development of a design. Instead, a BAL face seal was selected as it possessed excellent sealing properties, is readily available in the marketplace, and can withstand tremendous compressive forces, thereby allowing it to seal even in the case of reverse pressure.

MSC-740



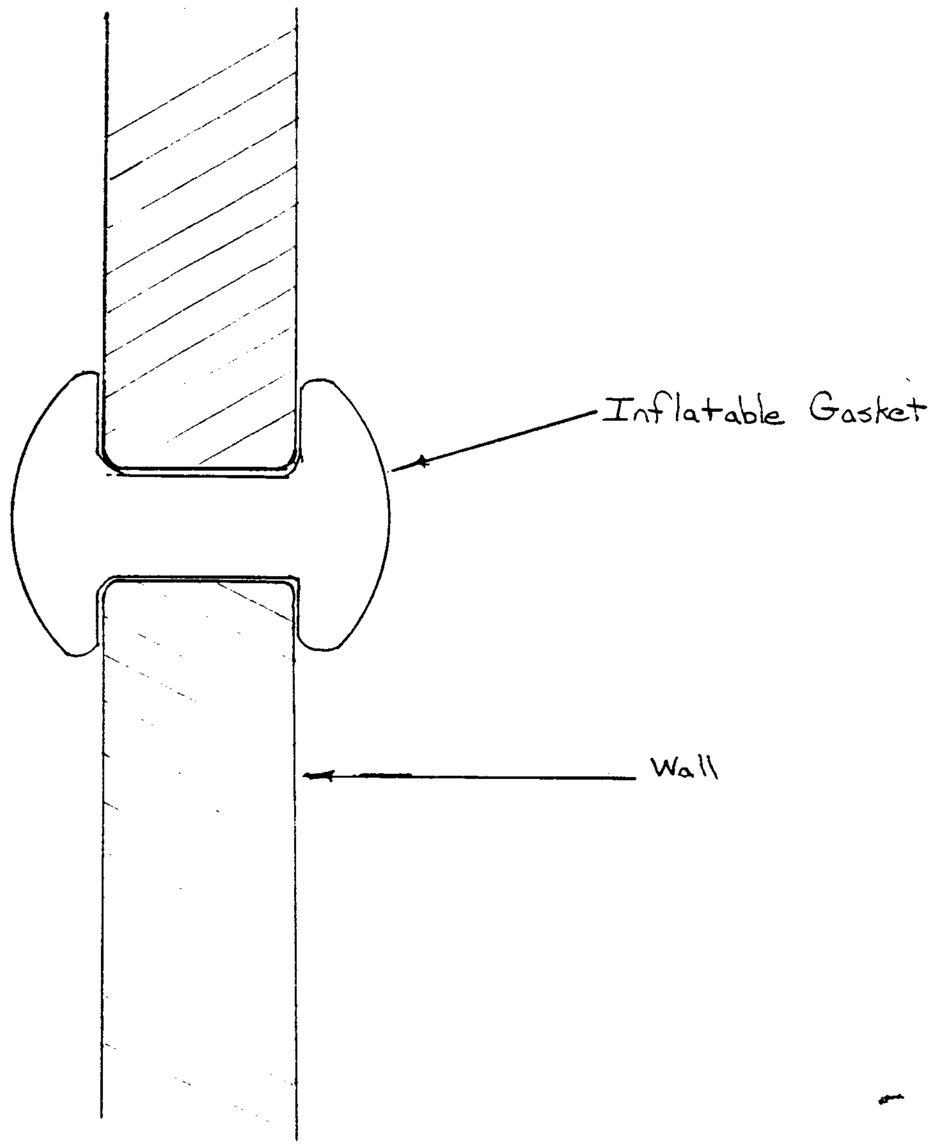
Allows a positive means of sealing without the manual application of large compressive forces. Used on some previous hatch designs.

If $\alpha = 0$, tough to get good origional seal.



Seal would not work well in reverse pressure gradient situation.

MFS - 12914



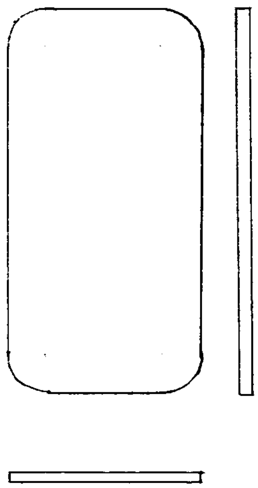
Danger of outside rupture of gasket.

Used on emergency escape hatch in previous space vehicles.

APPENDIX 4-C HATCH DOORS

Rough sketches of a variety of hatch door configurations initially considered in this project follow.

PLATE



DOMED PLATE

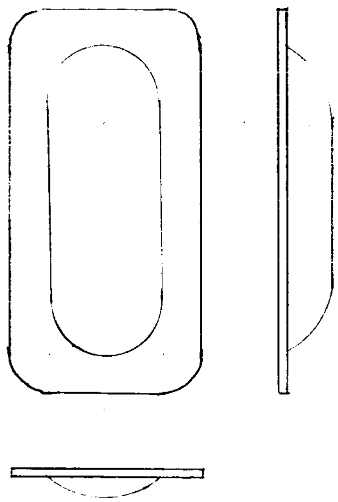
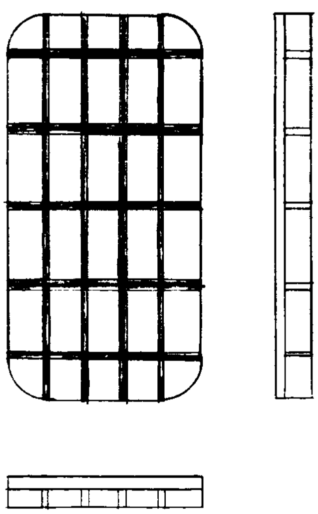
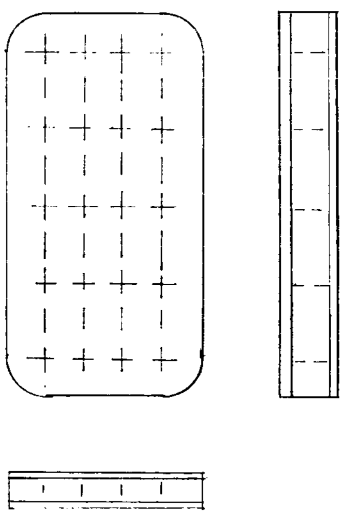


PLATE WITH STIFFENERS

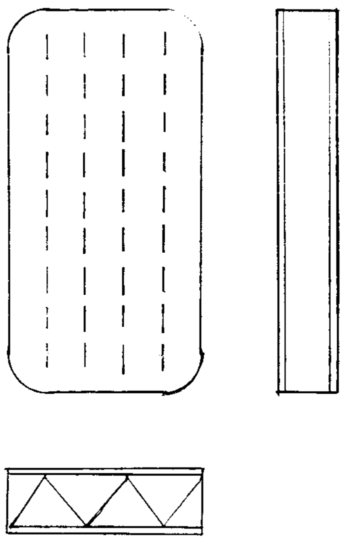


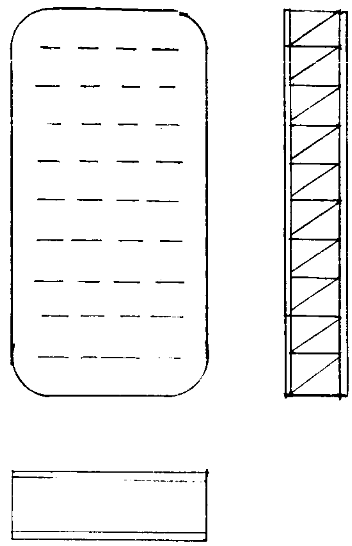
TWO PLATES W/ STIFFENERS



TWO PLATES

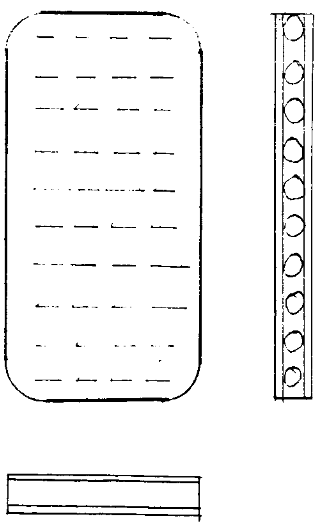
CORREGATED



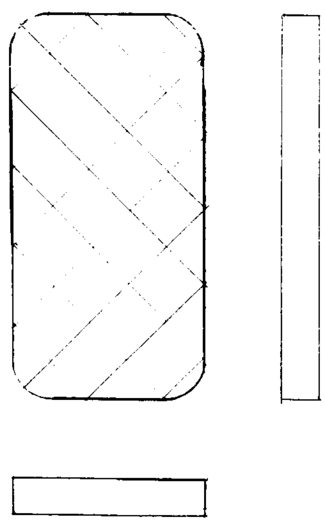


COMPOSITES

TUBULAR

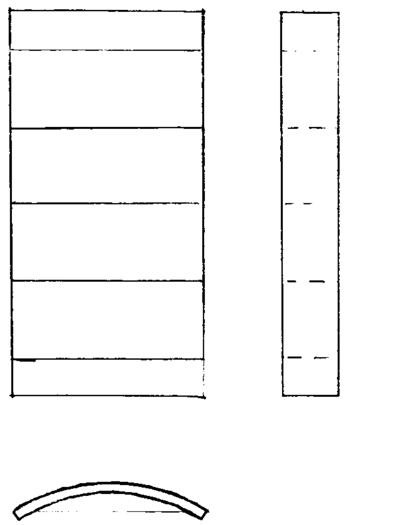


HONEYCOMB

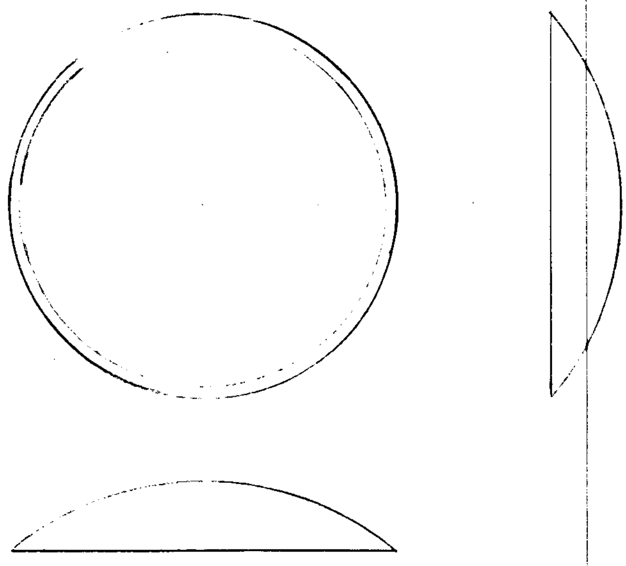


CYLINDRICAL

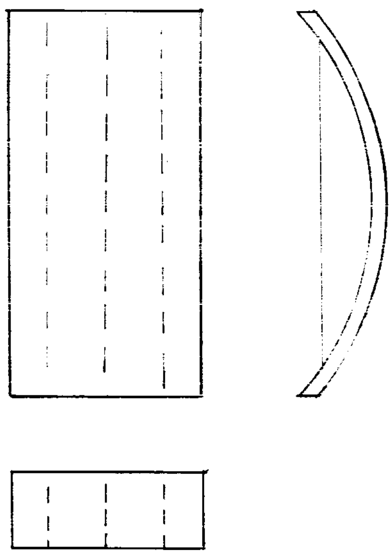
REINFORCED SHELL



SPHERICAL
SHELL

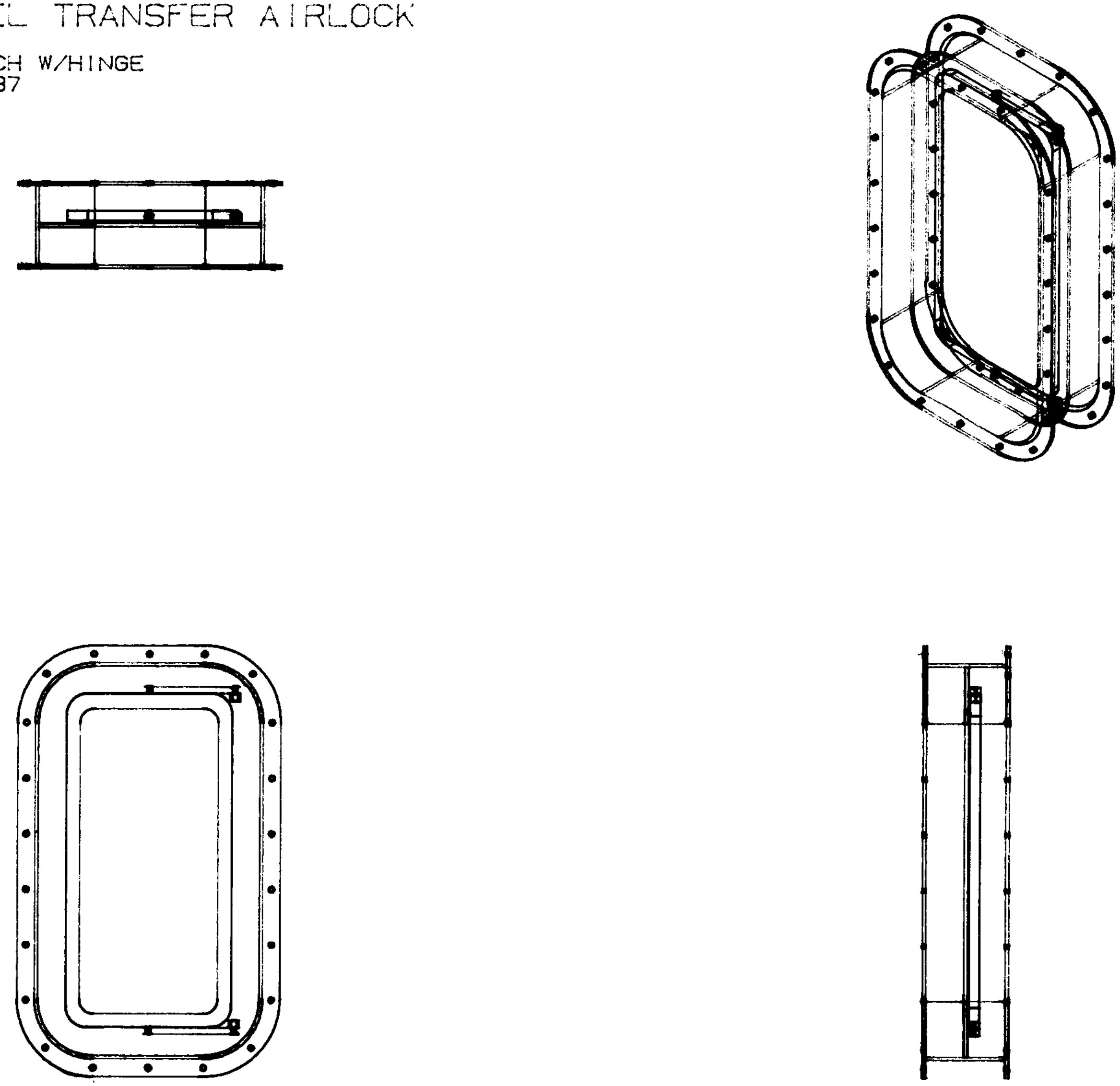


CYLINDRICAL



SHELLS:
- Light weight
- hard to attach hardware

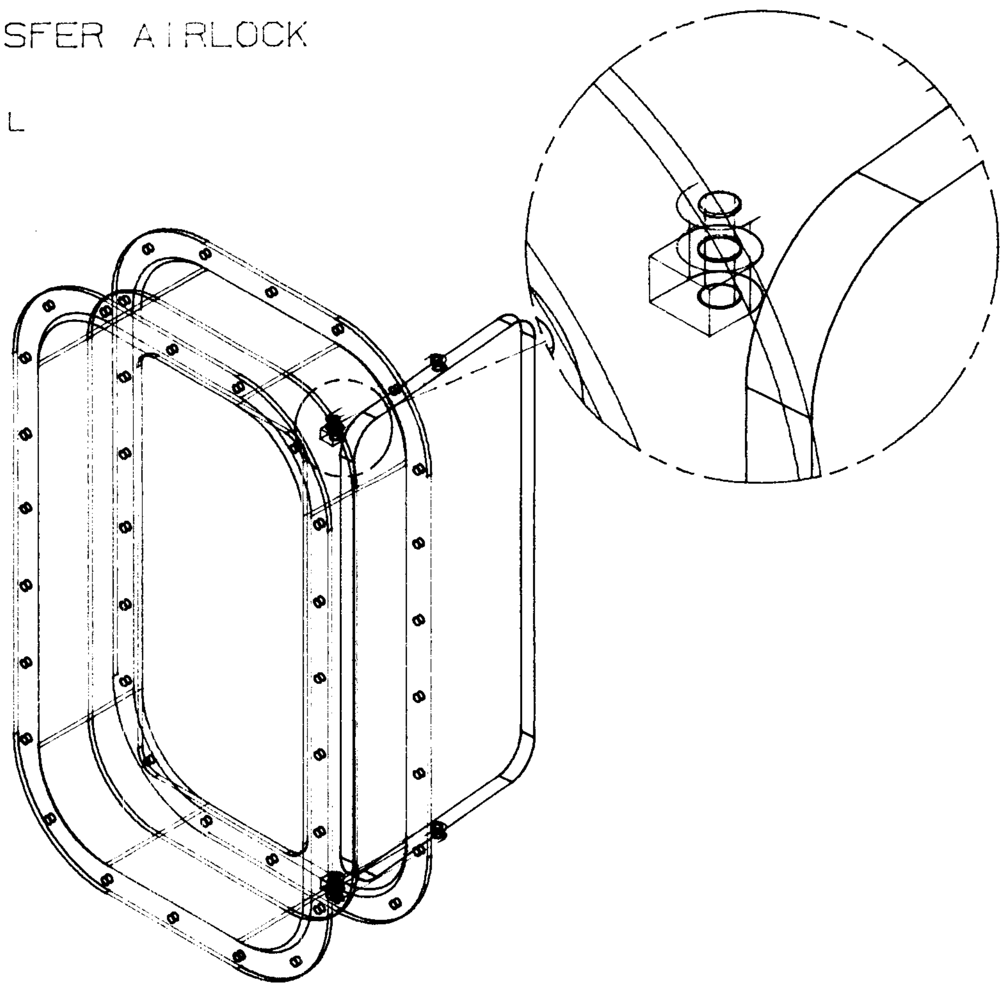
PERSONNEL TRANSFER AIRLOCK
GROUP 1
MODULAR HATCH W/HINGE
DATE: 4/27/87

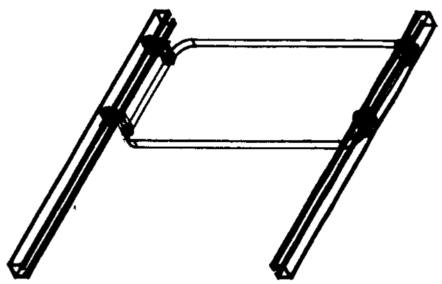
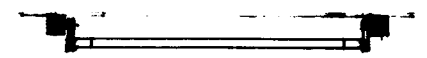


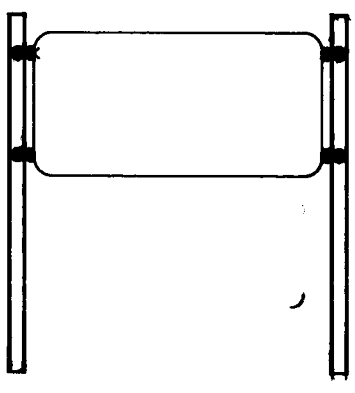
GT38 87/04/30. 10.51.52. ALLS

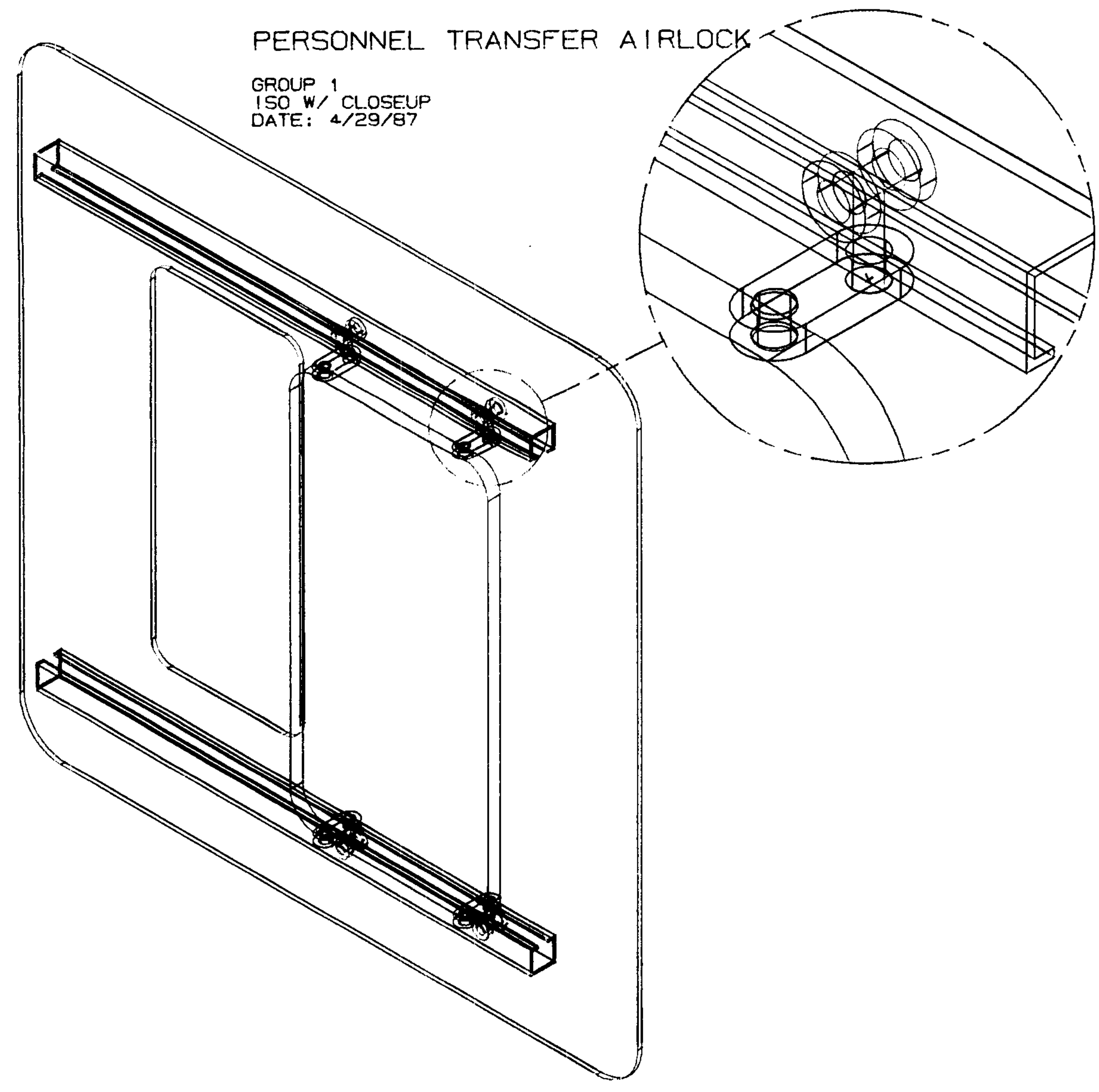
PERSONNEL TRANSFER AIRLOCK

GROUP 1
ISO VIEW WITH DETAIL
DATE: 4/29/87

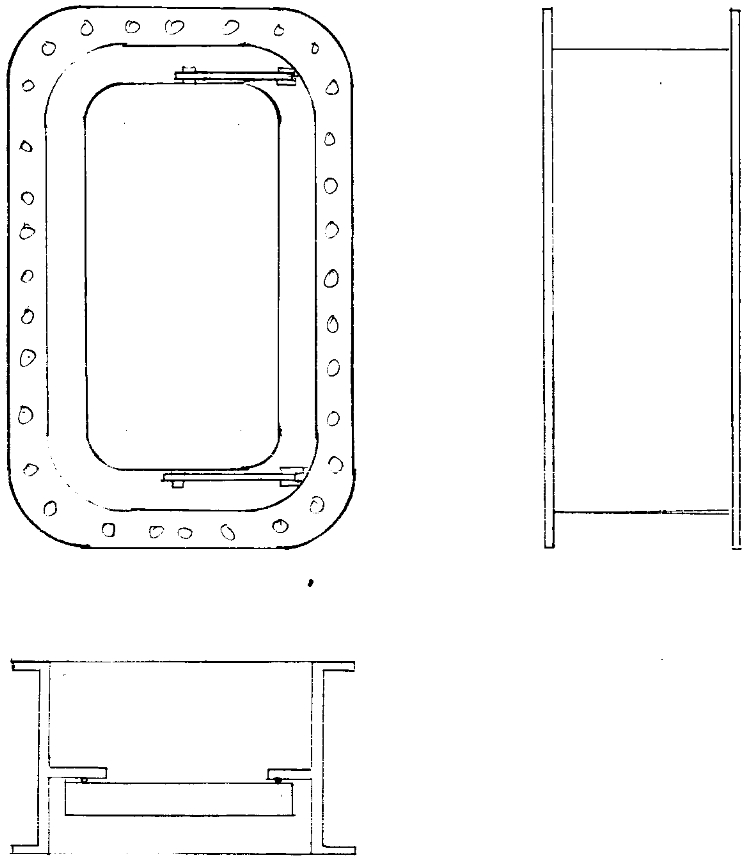




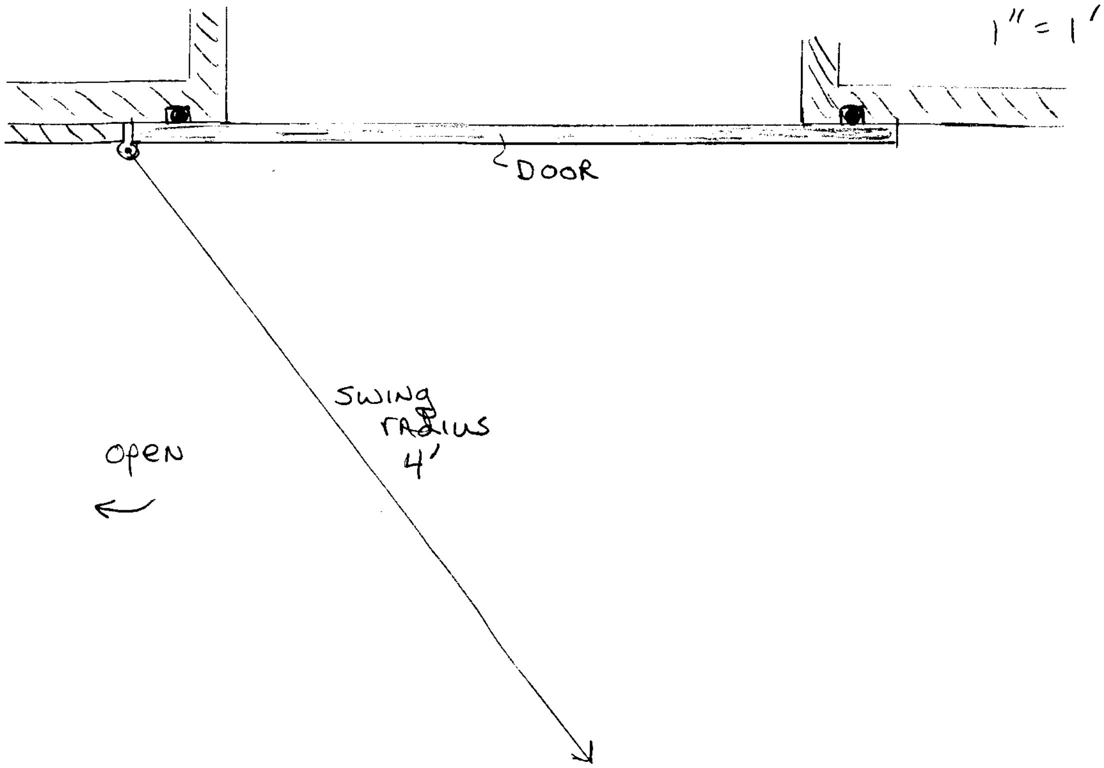

PERSONNEL TRANSFER AIRLOCK
GROUP 1
ISO W/ CLOSEUP
DATE: 4/29/87

UNIVERSAL HATCH DOOR



STANDARD HINGED SWING DOOR

3' x 7' opening
4' x 8' door



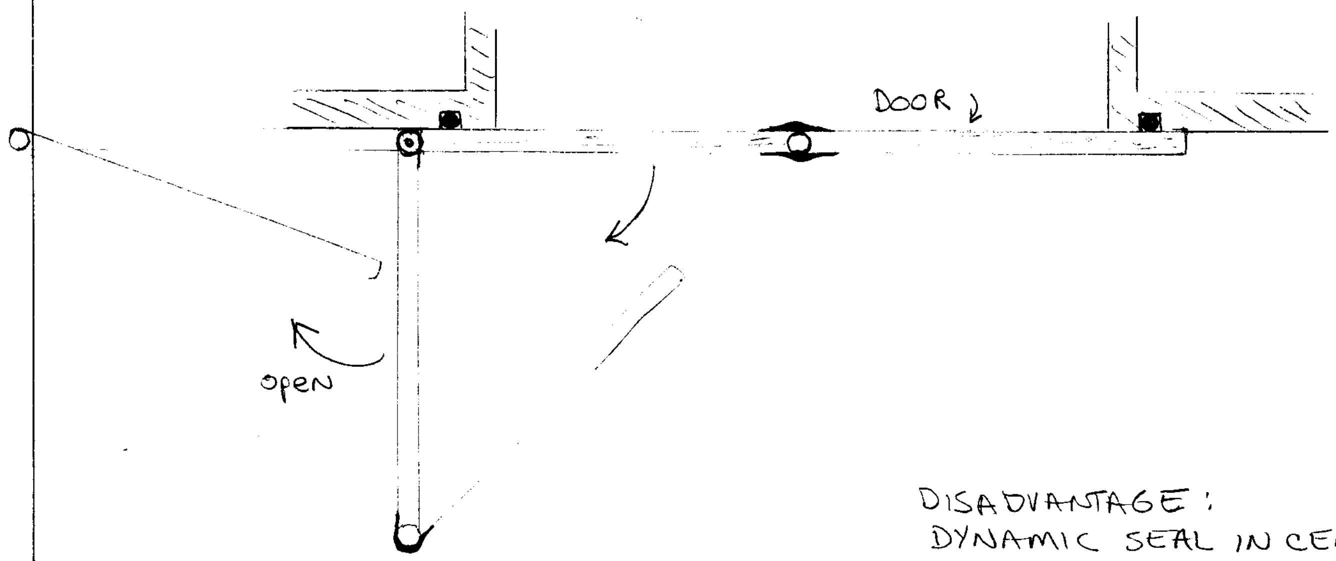
This door could swing ≈ 180° to rest against wall.

Disadvantage: wide area required for swing.

Advantage: static seal

FOLDING DOOR

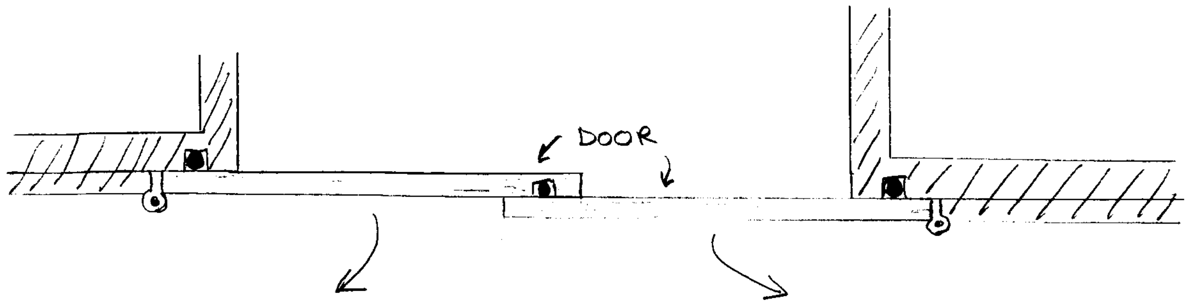
1" = 1'



DISADVANTAGE:
DYNAMIC SEAL IN CENTER
MORE SEAL AREA

ADVANTAGE:
REQUIRES LESS SPACE
FOR OPENING.

SPLIT DOOR

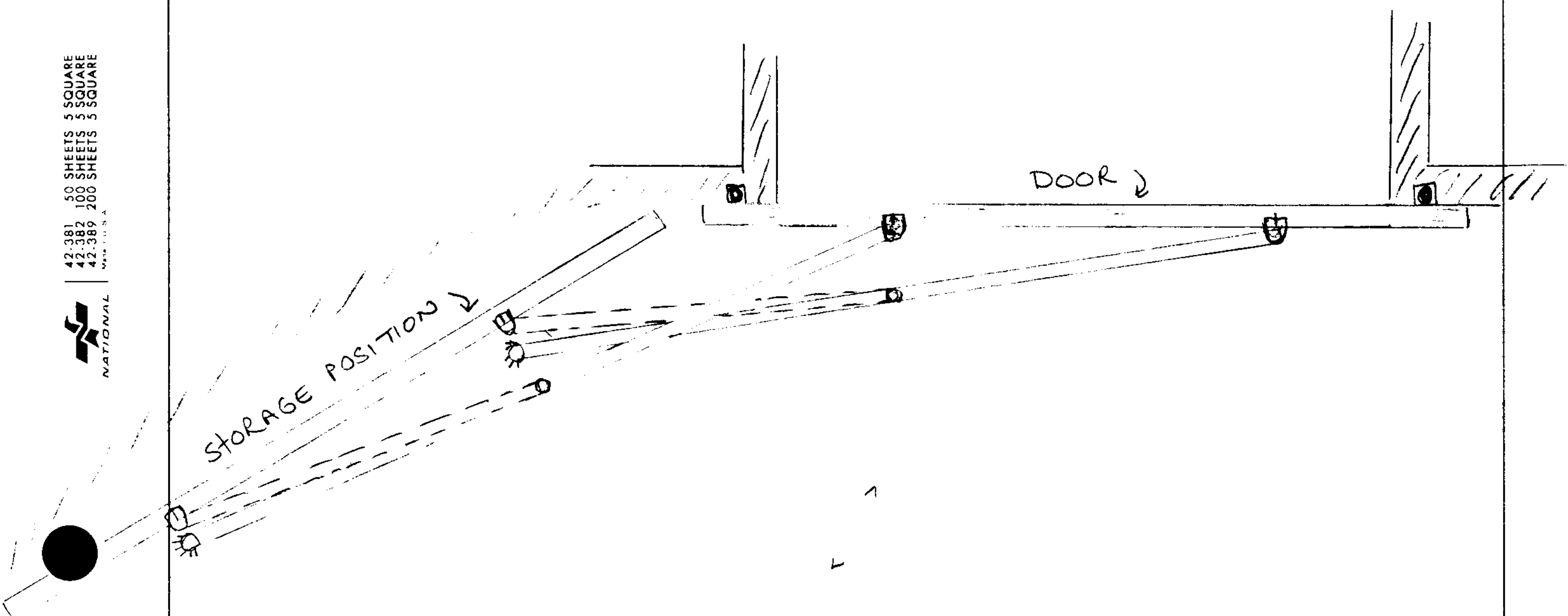


This door could be split on the horizontal with the top lifting up and the bottom folding down.

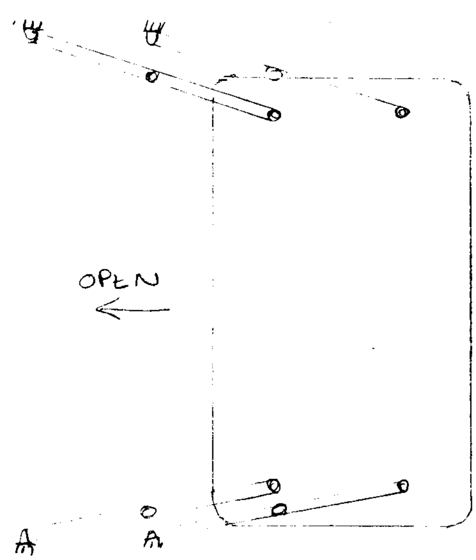
ADVANTAGE: REQUIRES LESS SPACE FOR OPENING. LESS STRESS ON EACH HINGE. STATIC SEAL.

DISADVANTAGE: MORE SEAL AREA. DIFFICULTING IN SUPPORTING DOOR CENTER FOR SATISFACTORY SEAL.

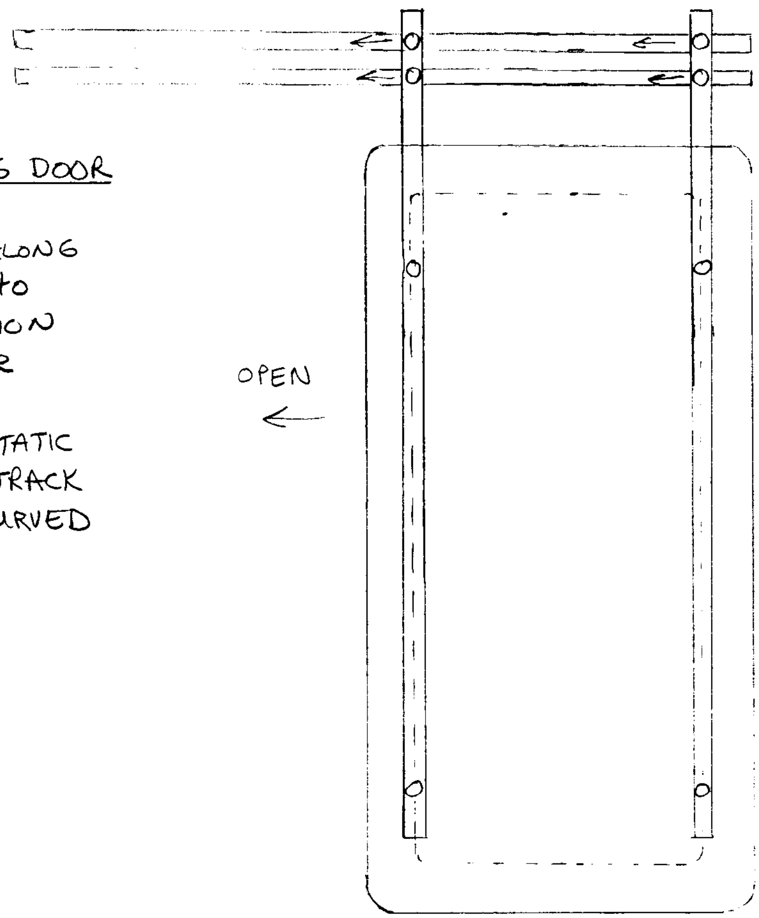
DOOR WITH LINKAGE MECHANISM



ADVANTAGE;
STATIC SEAL

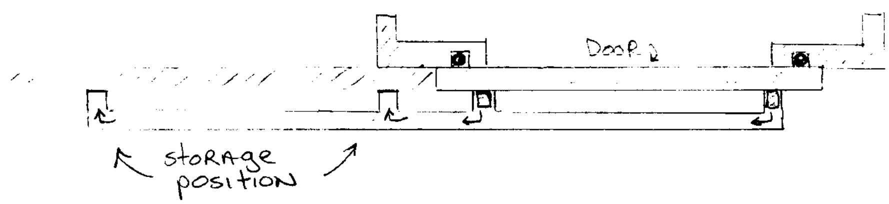


1" = 2'

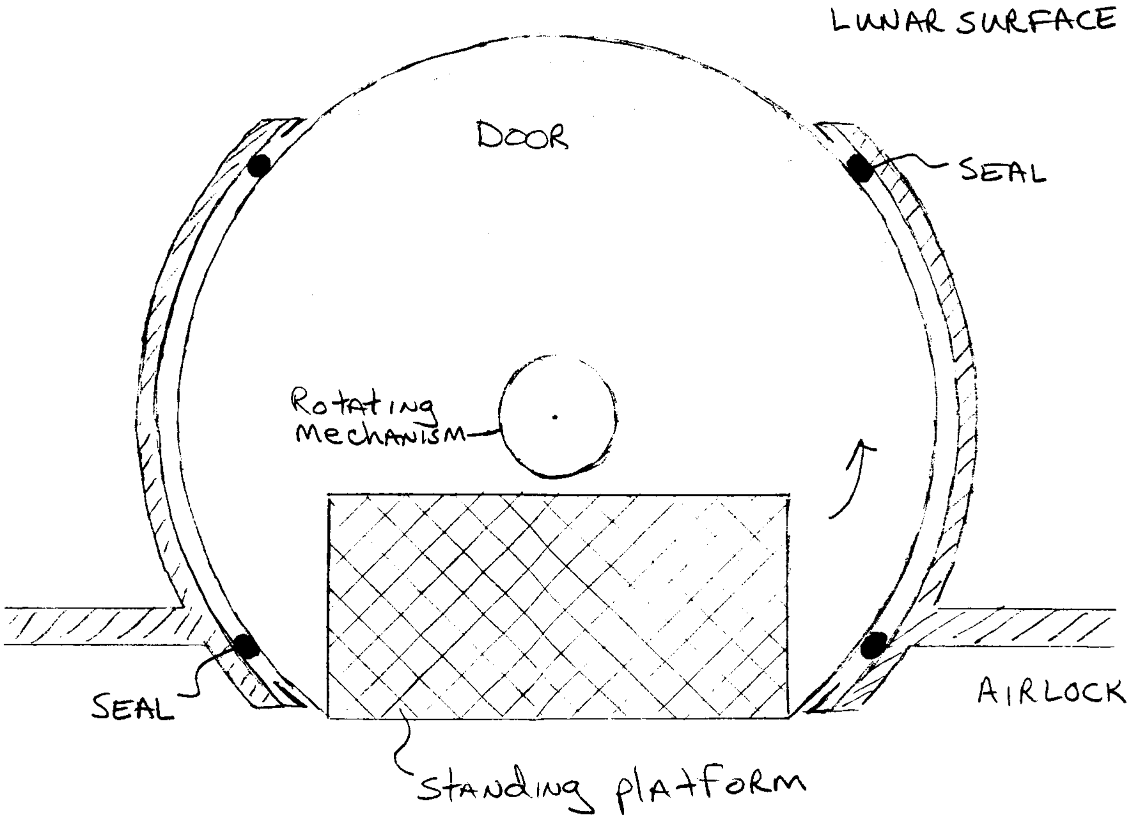


SLIDING HUNG DOOR

DOOR SLIDES ALONG TRACK AND into closed position OR storage position.
ADVANTAGE; STATIC SEAL. THIS TRACK COULD BE CURVED



ROTATING DOOR



DISADVANTAGE:
  DYNAMIC SEALS
  Rotating Mechanism
    more complicated design

APPENDIX 5 WEEKLY PROGRESS REPORTS

MEMORANDUM

DATE: April 10, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on April 3, 1987, at which time basic concepts were discussed. Vince Cassisi, a NASA representative, was contacted by telephone to obtain initial information about the project. Another group meeting was held on April 7, 1987, to determine basic assumptions, objectives, and constraints relative to the project as a result of the initial research by the team members.

2. Tim Cory investigated current vacuum technology related to space simulation and searched available information on the Apollo and space shuttle missions.

3. Capel English drafted preliminary conceptual designs of the hatch flange for the lunar module using the ICEM drafting utility on CYBER D.

4. Rose Hardman identified the initial submittal requirements for the project and investigated recent developments in lunar bases and information on the lunar environment.

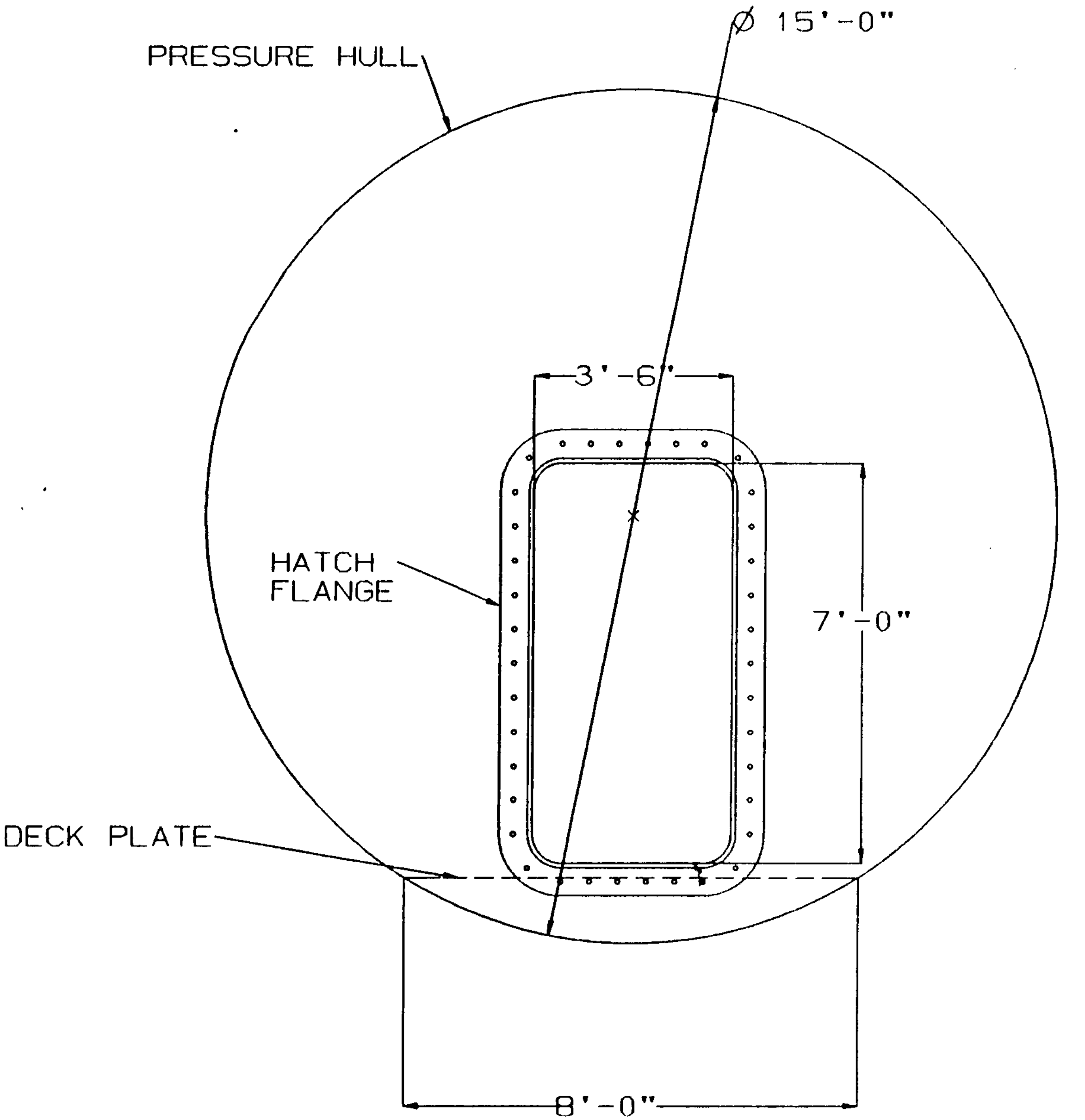
5. Joanna Martinez researched current clean room technology and design criteria with particular emphasis on that used in silicon chip manufacturing and in hospitals.

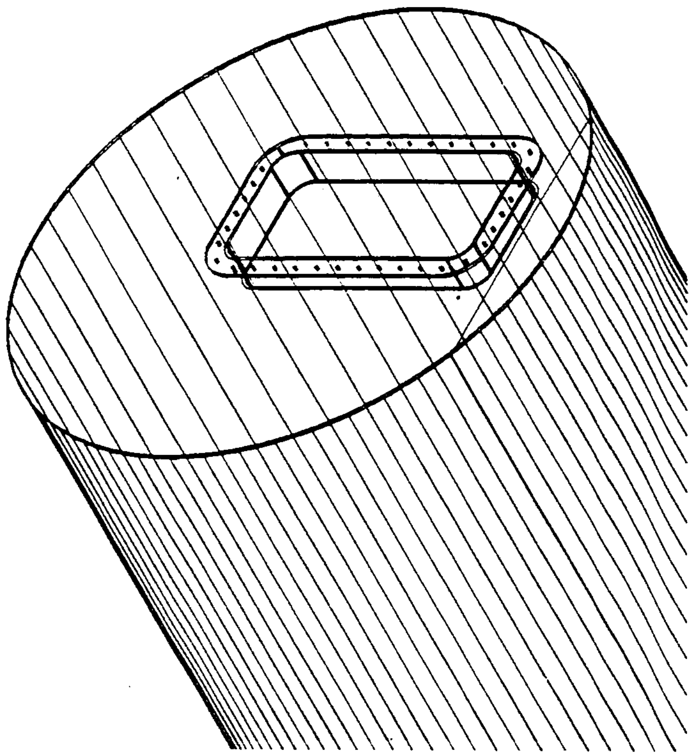
6. Kevin Moss investigated gasket materials available for vacuum seals. The NASA contract, NAS 7-102, concerning new materials for gaskets was reviewed.

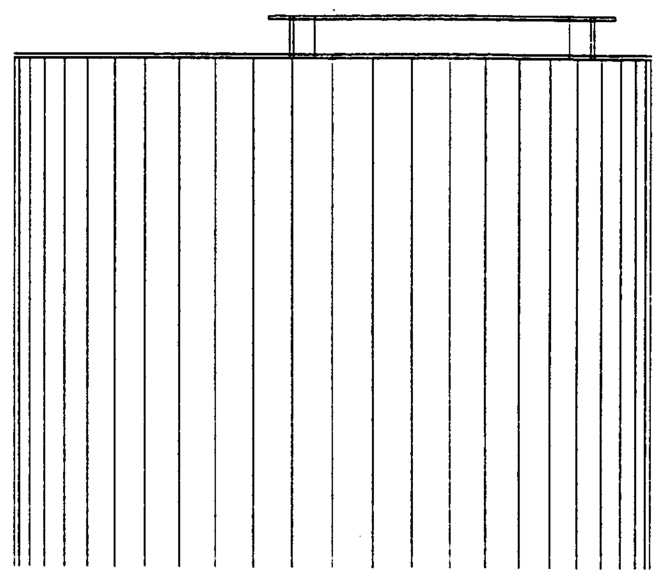
7. Mike Wileman obtained information on the technology currently employed for production and measurement of vacuums at various levels.

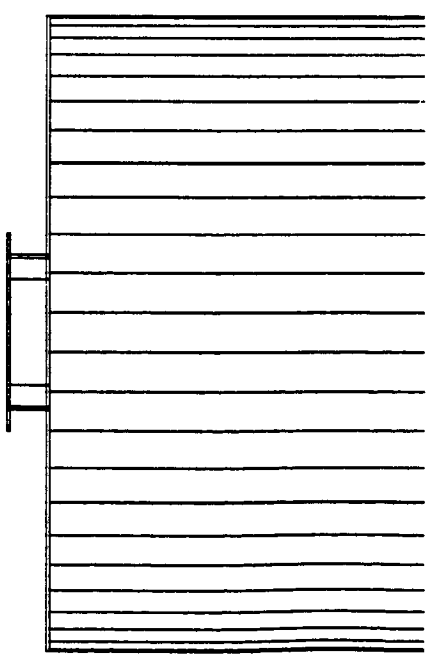
8. Mark Wolaver researched existing airlocks and hatches in reference to possible limitations applicable to this project.

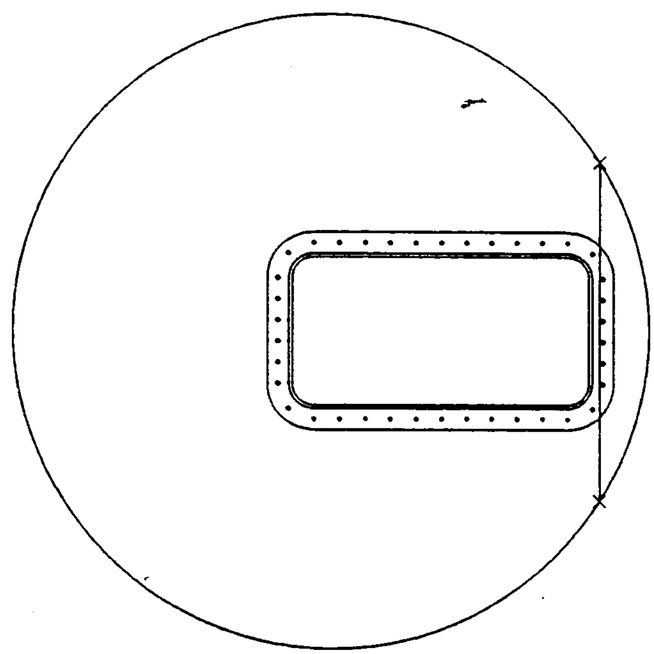
4/10/87
GROUP 1
CONCEPTUAL DESIGN OF
LUNAR MODULE AIRLOCK
FLANGE











MEMORANDUM

DATE: April 17, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on April 10, 1987 at which time different approaches to the entry/exit hatches were discussed. Several new types of doors were discussed but no final conclusions were drawn. The possibility of using modular doors was also discussed. Another group meeting was held on April 14, 1987. At this meeting various possibilities for the geometry of the airlock and its entry/exit were discussed. It was also decided that several team members would investigate the feasibility of modular doors.

2. Tim Cory constructed a graph depicting the amount of volume required for various numbers of people for each of the geometries available for the airlock.

3. Capel English contacted Custom Seal Company in Atlanta regarding vacuum-air seals and came up with a conceptual design for the hatch door seal/lock mechanism. He also performed a FEM analysis of the conceptual door.

4. Rose Hardman investigated problems of the lunar module used in the NASA Apollo missions. She also developed an expandable cylinder arrangement for possible airlock design.

5. Joanna Martinez investigated several clean room designs and proposed ideas for systems which may be used in the airlock.

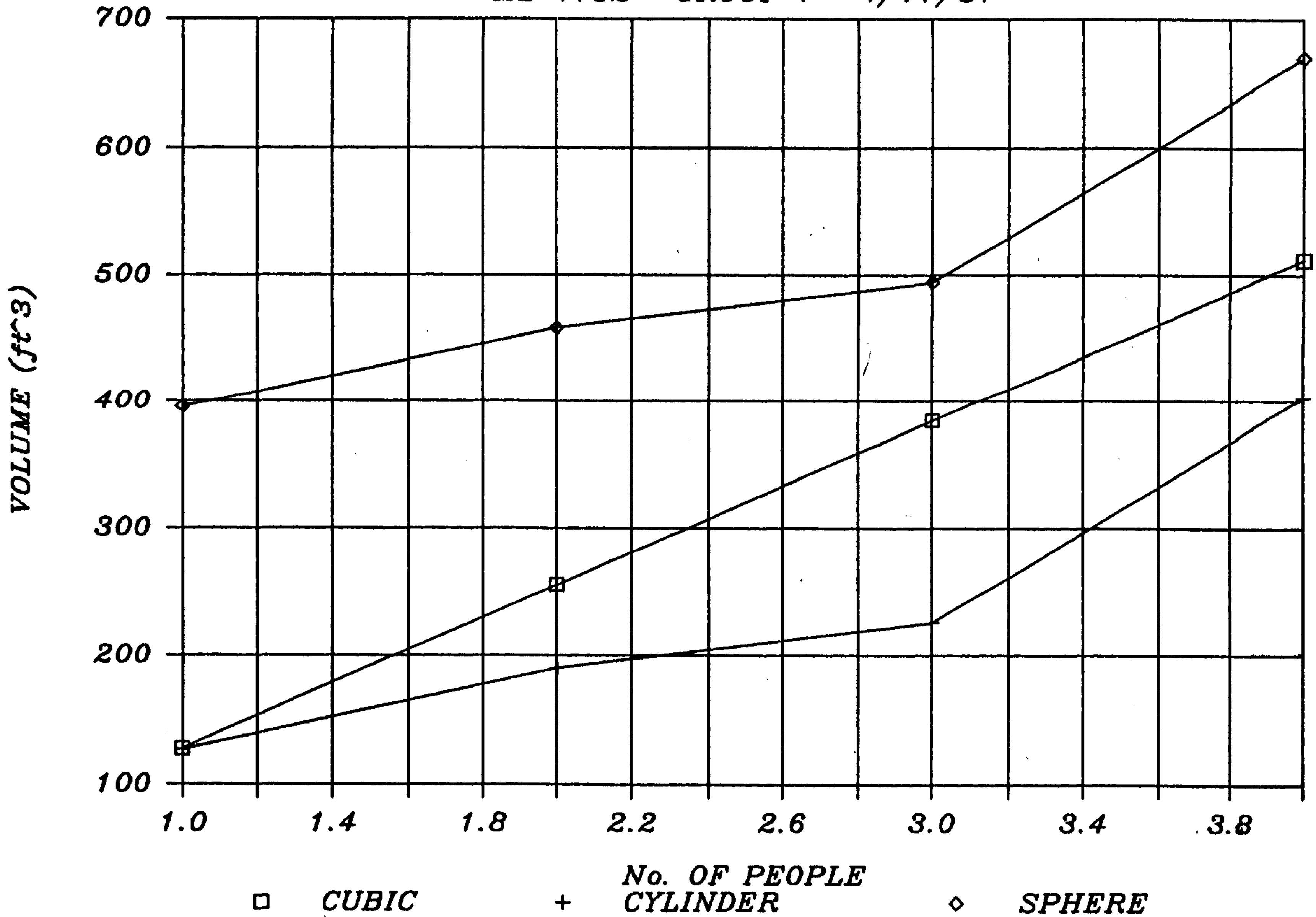
6. Kevin Moss worked on a design of an airlock that would allow minimum loss of air while decreasing pump-down time. He also contacted National O-Ring, Inc., to get a compound recommendation for vacuum seals.

7. Mile Wileman began developing a numerical model of evacuation time as a function of volume and number of people in the airlock.

8. Mark Wolaver did specific research on particulate removal filter types, gasket materials, and strengths of applicable materials.

AIRLOCK VOLUME/VARIOUS GEOMETRIES

ME 4182 GROUP 1 4/17/87



MEMORANDUM

DATE: April 24, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Pcrsonnel Transfer Airlock

1. A group meeting was held on April 17, 1987, with Mr. Brazell Different types of hatch, airlock, and system geometries which would better tend to fit the needs of the NASA program were discussed. It was decided that two approaches would be investigated for the hatch design. One design would utilize modular doors and the other would have the doors built within the system. At a later date the best design will be selected for further development after discussing the alternatives with Vince Cassisi, our NASA representitive.

2. Tim Cory began drawings depicting concepts of airlock chambers of varying geometric shapes, including the location of air storage tank, vacuum pump, and other equipment.

3. Capel English completed post processing of the finite element analysis of the hatch door and plotted the results. He also made conceptual design drawings for various hatch door configurations.

4. Rose Hardman developed conceptual design drawings for a variety of linkage/hinge mechanisms applicable for attaching and maneuvering the hatch door.

5. Joanna Martinez researched U.S. patents for various door configurations, seals, and existing airlock designs.

6. Kevin Moss worked on conceptual designs for various types of seals to be used on the hatch doors and made drawings of several possible seal arrangements.

7. Mile Wileman continued development of the computer simulation pumping program and began entering pump performance curves into a database.

8. Mark Wolaver did specific research into hatches (personnel and equipment) being used in industry today, to include gasket alignments, interlocking mechanisms, reverse pressure mechanisms, and monorail systems.

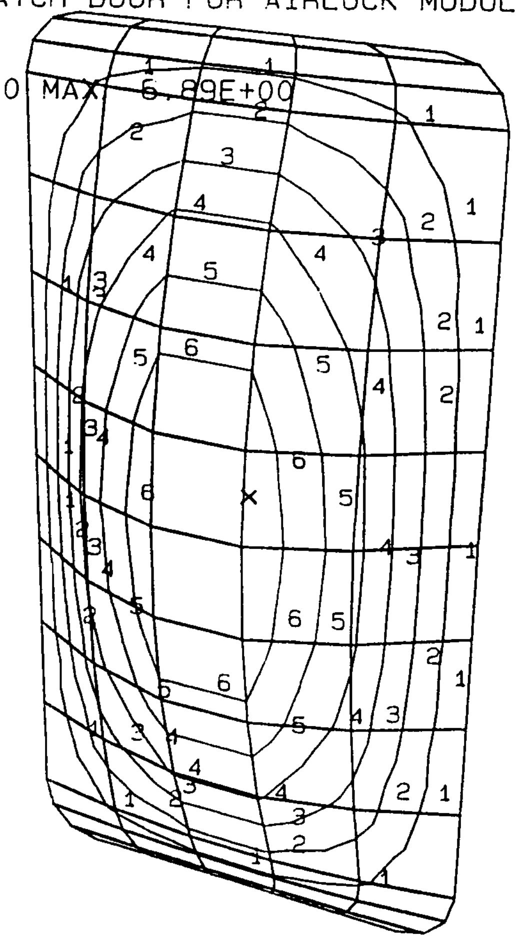
SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing

19-APR-87 20:25:40
UNITS = IN
DISPLAY: No stored OPTION

HATCH DOOR FOR AIRLOCK MODULE

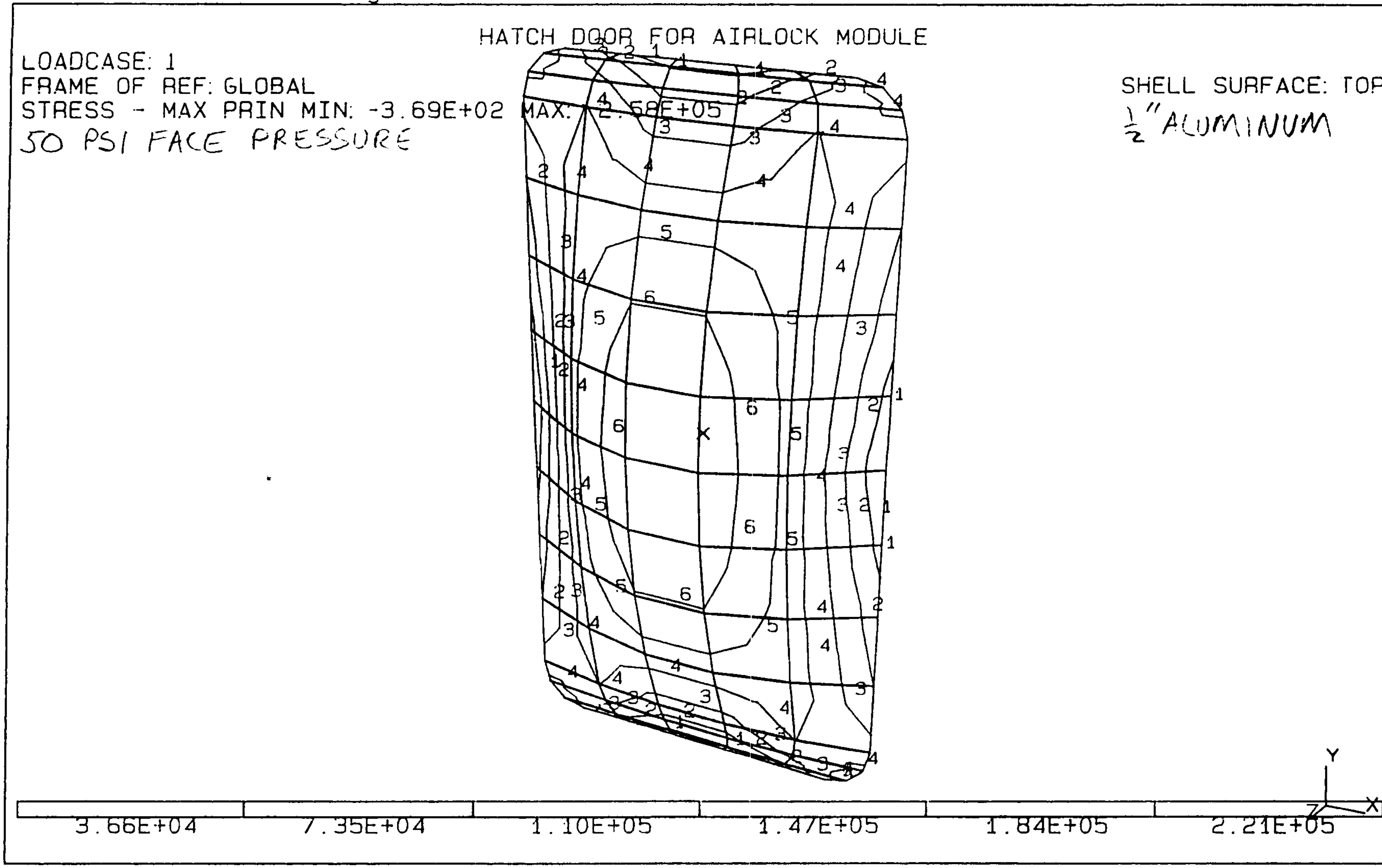
LOADCASE: 1
FRAME OF REF: GLOBAL
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 6.89E+00
50PSI FACE PRESSURE

SHELL SURFACE: TOP
1/2" ALUMINUM



9.85E-01	1.97E+00	2.95E+00	3.94E+00	4.92E+00	5.91E+00

SDRC I-DEAS 3.8: Pre/Post Processing 16-APR-87 21:01:12
DATABASE: HATCH DOOR FOR AIRLOCK MODULE UNITS = IN
VIEW: No stored VIEW DISPLAY: No stored OPTION
Task: Post Processing

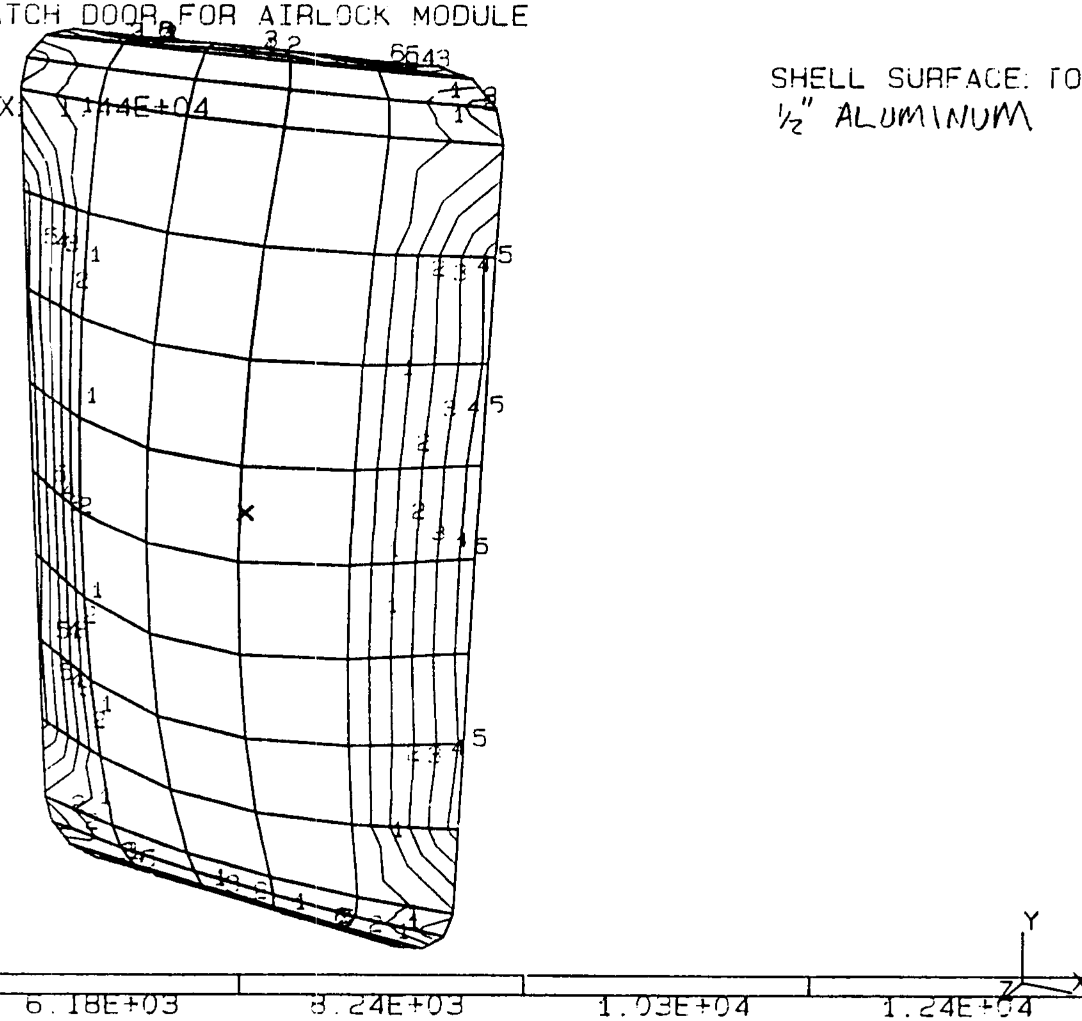


SDRC I-DEAS 3.8: Pre/Post Processing 19-APR-87 20:53:53
DATABASE: HATCH DOOR FOR AIRLOCK MODULE UNITS = IN
VIEW: No stored VIEW DISPLAY: No stored OPTION
Task: Post Processing

HATCH DOOR FOR AIRLOCK MODULE

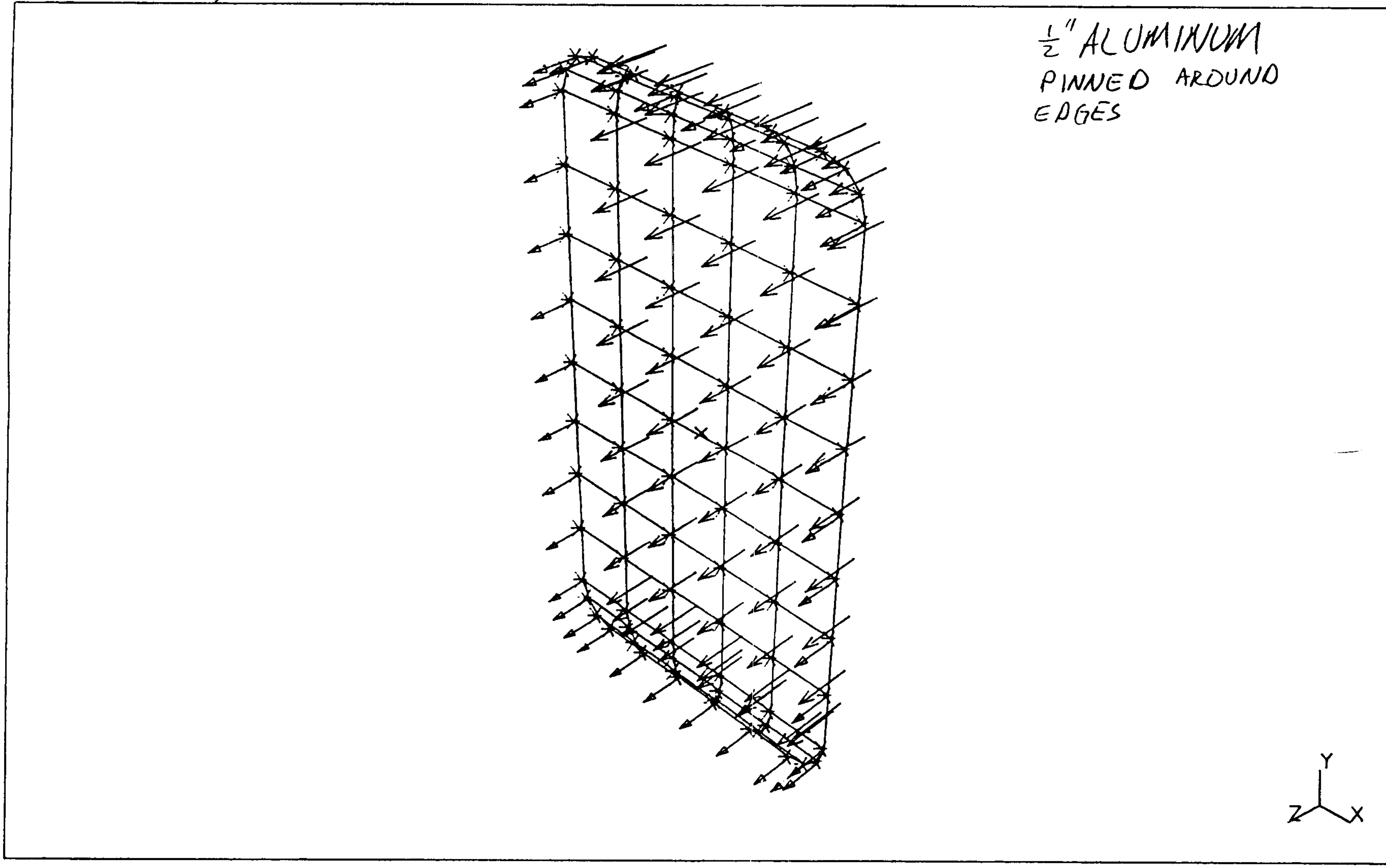
LOADCASE: 1
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 1.44E+04
50 PSI FACE PRESSURE

SHELL SURFACE: TOP
½" ALUMINUM



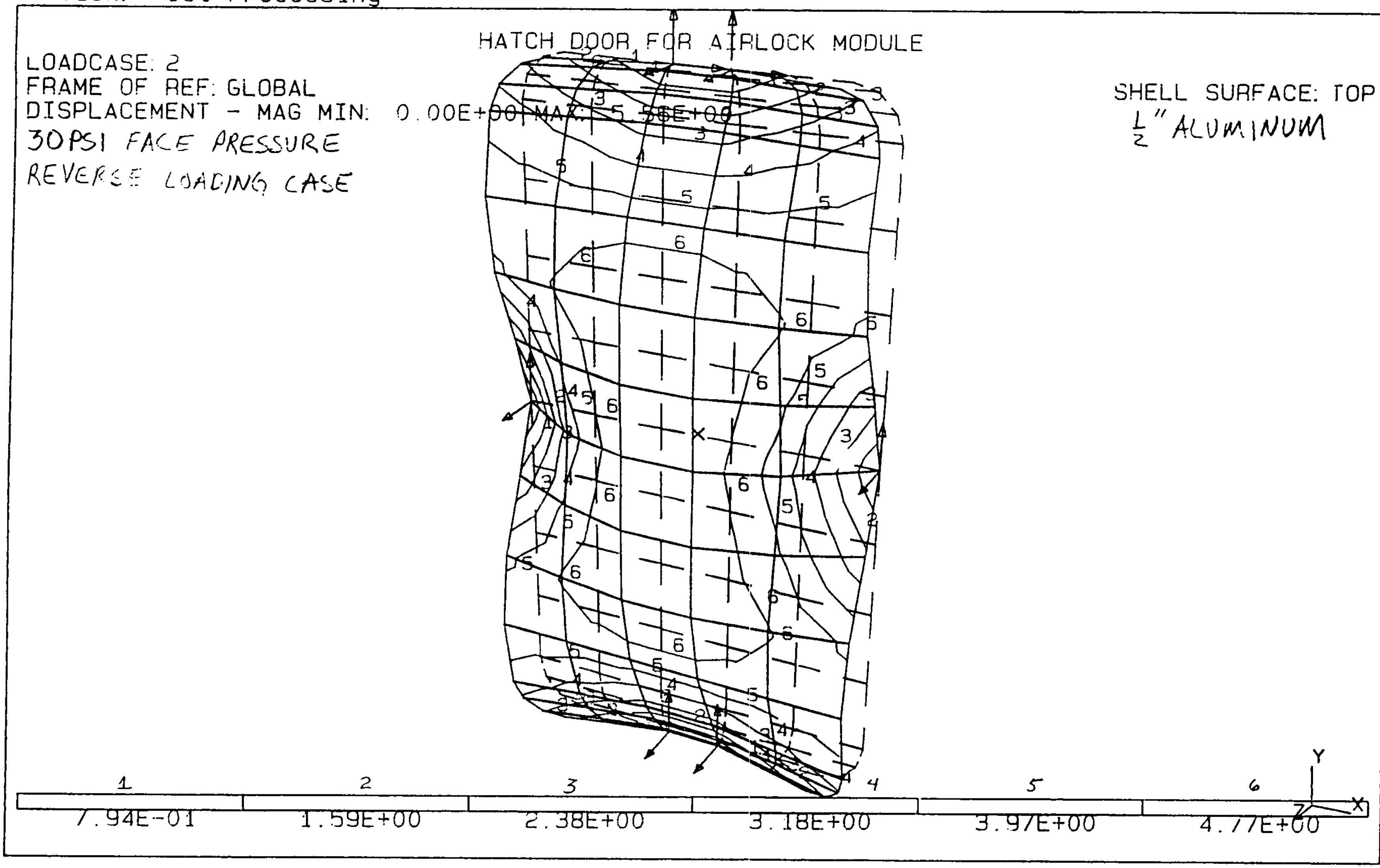
SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Analysis Cases

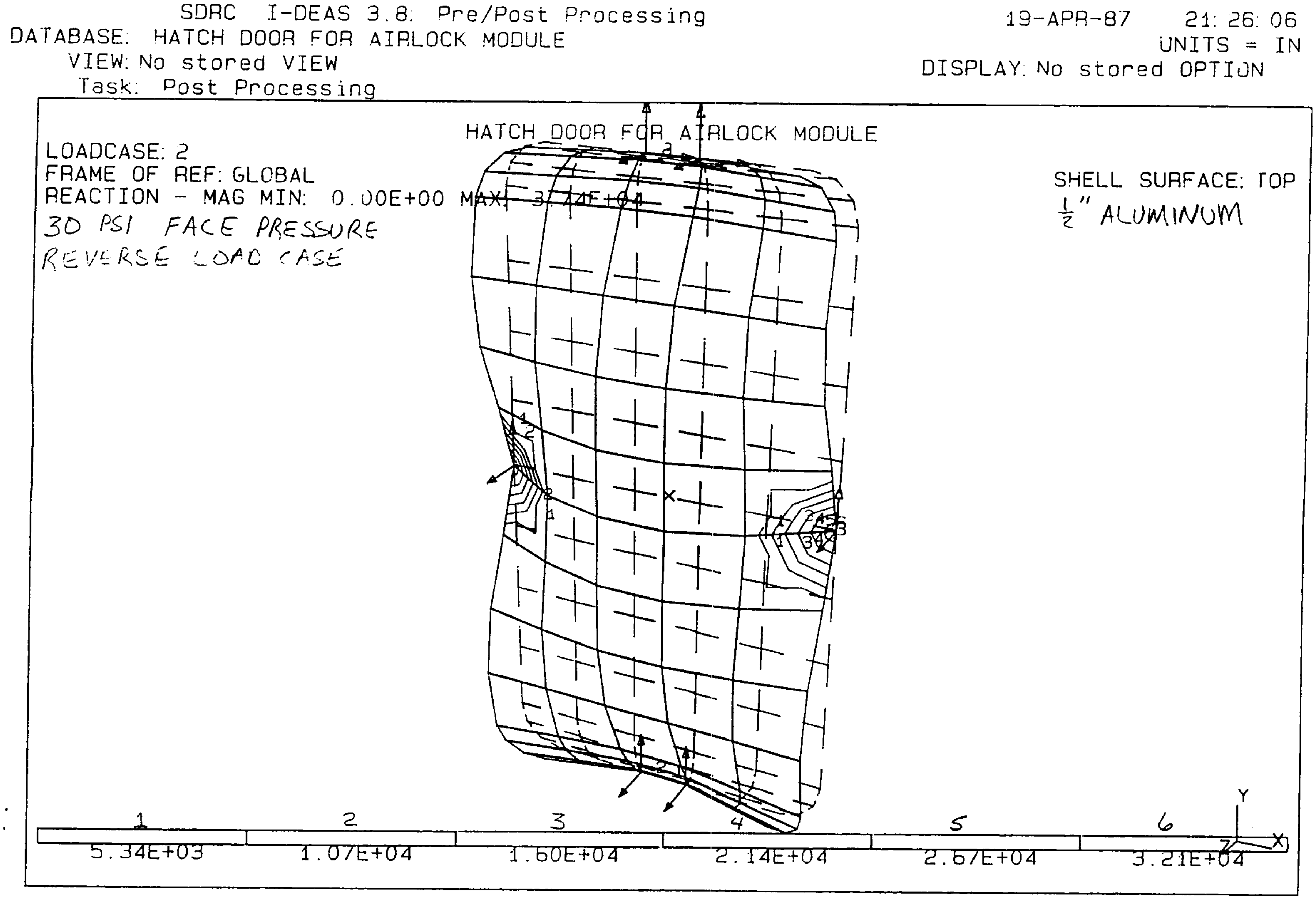
16-APR-87 13:38:47
UNITS = IN
DISPLAY: No stored OPTION

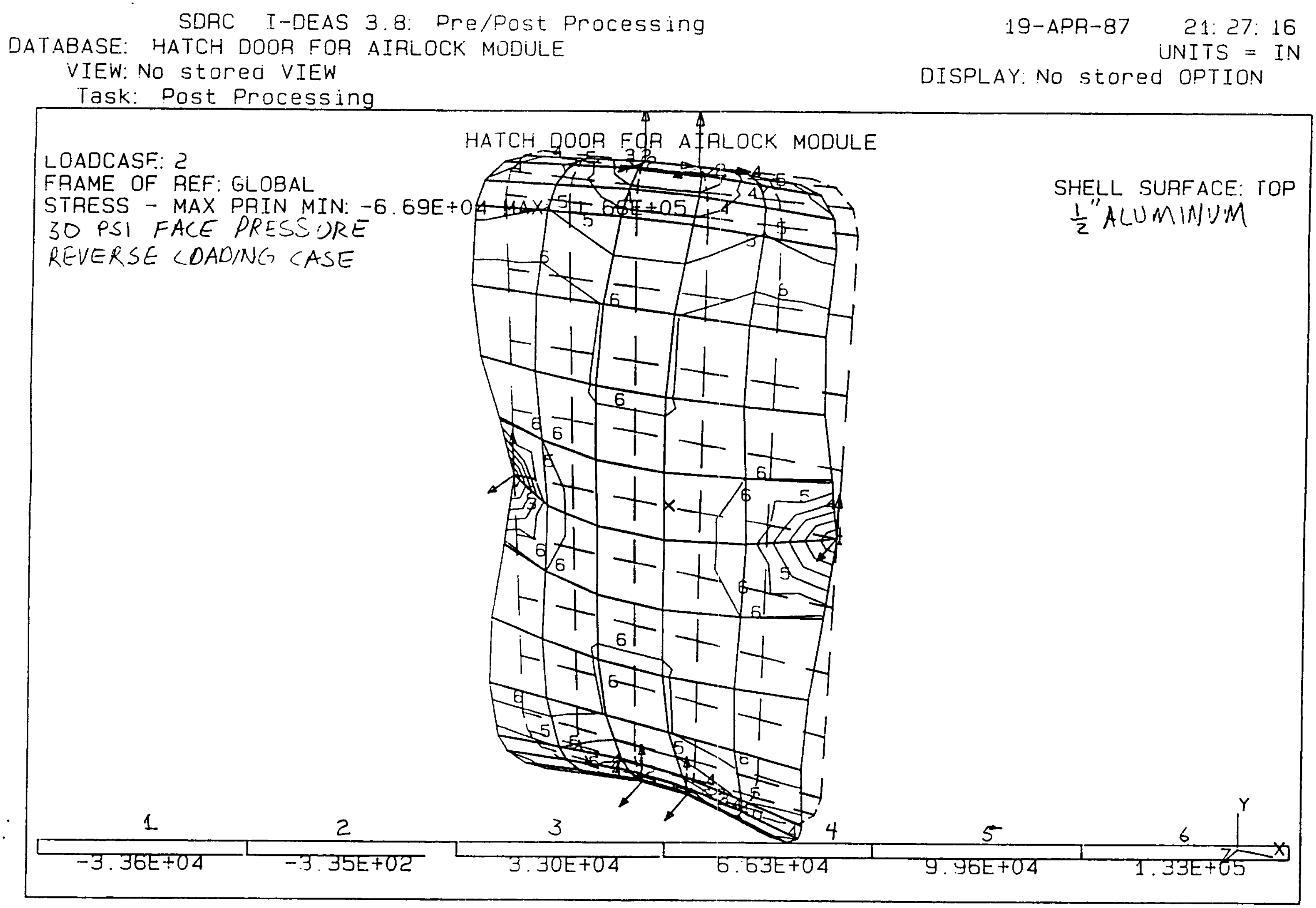


SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing

19-APR-87 21:23:06
UNITS = IN
DISPLAY: No stored OPTION




SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing
19-APR-87 21:26:06
UNITS = IN
DISPLAY: No stored OPTION
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 2
FRAME OF REF: GLOBAL
REACTION - MAG MIN: 0.00E+00 MAX: 3.74E+04
30 PSI FACE PRESSURE
REVERSE LOAD CASE
SHELL SURFACE: TOP
½" ALUMINUM
1 2 3 4 5 6
5.34E+03
1.07E+04
1.60E+04
2.14E+04
2.67E+04
3.21E+04
Y
X
Z



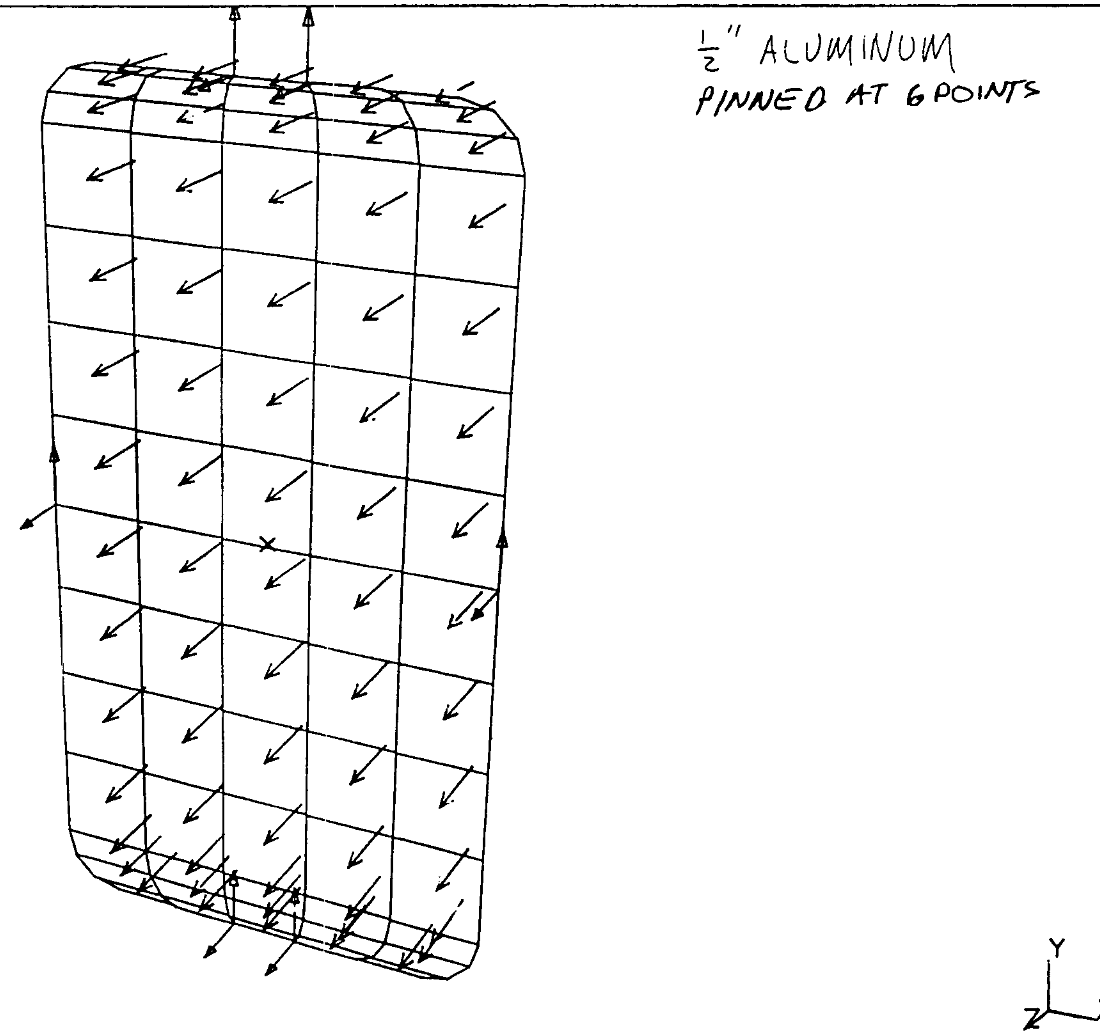
SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing
19-APR-87 21:27:16
UNITS = IN
DISPLAY: No stored OPTION
HATCH DOOR FOR AIRLOCK MODULE
LOADCASE: 2
FRAME OF REF: GLOBAL
STRESS - MAX PRIN MIN: -6.69E+04 MAX: 1.66E+05
30 PSI FACE PRESSURE
REVERSE LOADING CASE
SHELL SURFACE: TOP
1/2" ALUMINUM
1 -3.36E+04
2 -3.35E+02
3 3.30E+04
4 6.63E+04
5 9.96E+04
6 1.33E+05
Y
X
Z

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: HATCH DOOR FOR AIRLOCK MODULE
VIEW: No stored VIEW
Task: Post Processing

19-APR-87 20:34:54
UNITS = IN
DISPLAY: No stored OPTION

LOAD CASE #2
30 PSI FACE PRESSURE
REVERSE LOAD CASE

$\frac{1}{2}$" ALUMINUM
PINNED AT 6 POINTS



MEMORANDUM

DATE: April 30, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Gary McMurray on April 24, 1987 at which time the different types of hatch, airlock, and system geometries that had been discussed within the group were reviewed. Another group meeting was held on April 26, 1987. During this meeting the outline for the oral report was organized. The group met again on April 28, 1987, to finalize the oral report to be given on April 30, 1987.

2. Tim Cory prepared a synopsis of possible geometric shapes available for the airlock design. He also prepared a conceptual drawing of the most recent airlock shape discussed.

3. Capel English established preliminary hatch door designs using ICEM. Concepts included a hinge door on a modular hatch and a sliding door on an integrated hatch.

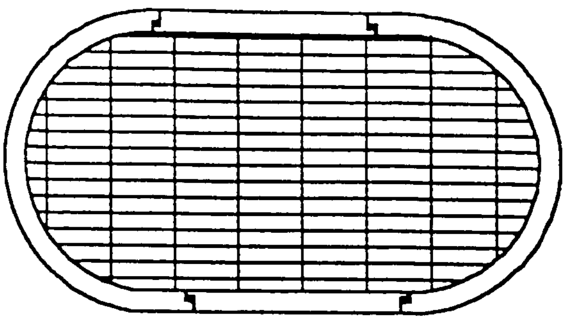
4. Rose.Hardman prepared and delivered the library search request and assisted in entering the pump data into the computer pump simulation database. She also prepared the final report outline with Joanna Martinez.

5. Joanna Martinez prepared the final report outline with Rose Hardman. She also compiled information and provided an outline on a proposed clean room design to be discussed in the oral report.

6. Kevin Moss compiled information on available materials that are currently used in seal design. He also specified characteristics that will be required of the material chose for the airlock seal.

7. Mile Wileman completed the computer simulation program and pump database and prepared a comparison of the available pumps. He also organized the information for the oral presentation.

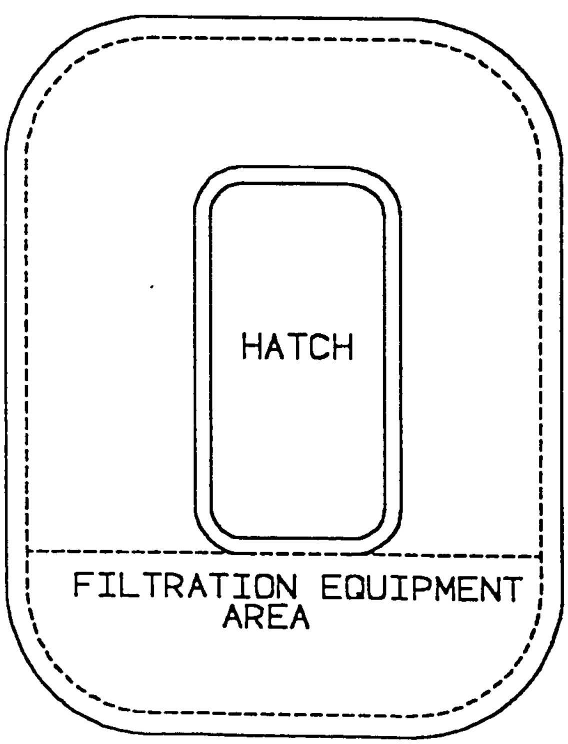
8. Mark Wolaver consolidated all the group data on the hatch design for the oral report. He also researched existing locking and saftey interlock mechanisms for the hatch doors.



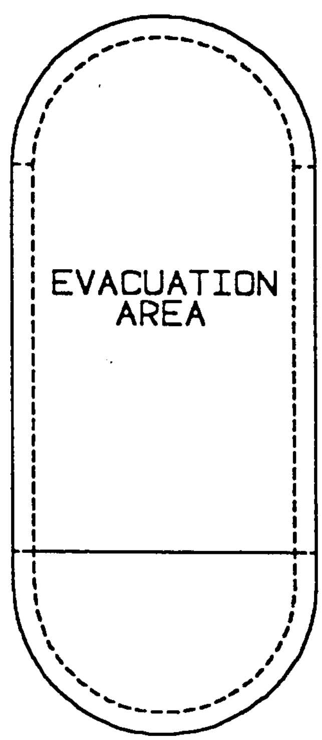
PLAN VIEW

PERSONNEL TRANSFER AIRLOCK
GROUP I
TITLE: INTEGRATED AIRLOCK DESIGN
DATE DESIGNED: 4/26/87

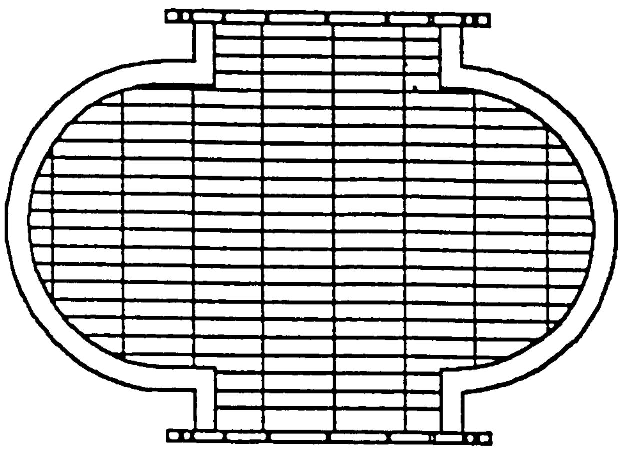
NOTE: CROSS-HATCHED AREA
INDICATES GRATING FLOOR



FRONT VIEW



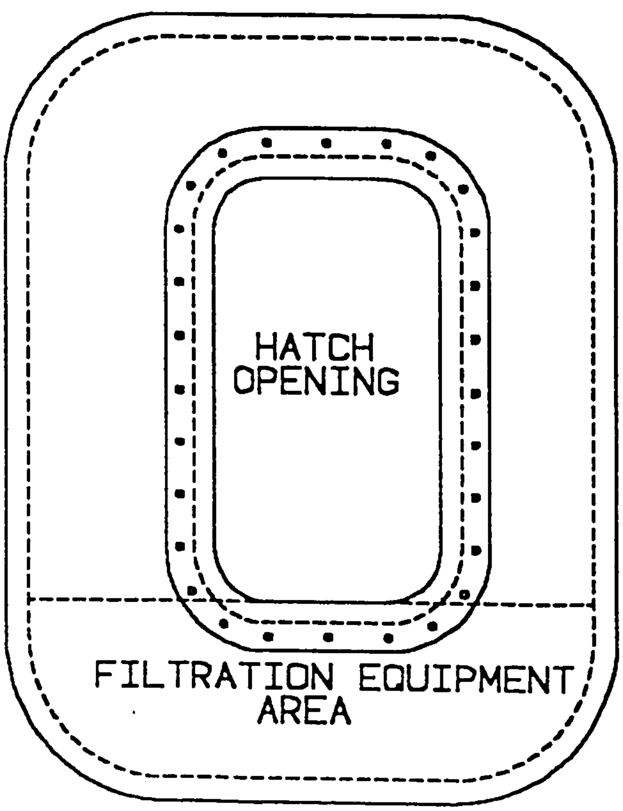
RIGHT VIEW



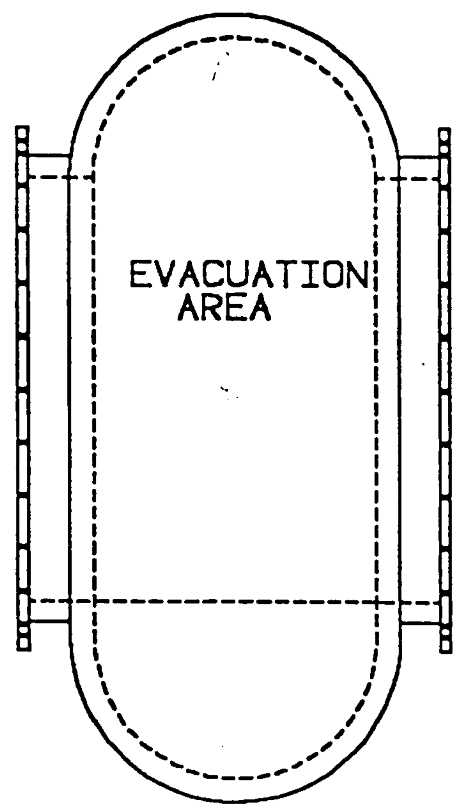
PLAN VIEW

NOTE: CROSS-HATCHED AREA
INDICATES GRATING FLOOR

PERSONNEL TRANSFER AIRLOCK
GROUP I
TITLE: MODULAR AIRLOCK DESIGN
DATE DESIGNED: 4/26/87



FRONT VIEW



RIGHT VIEW

MEMORANDUM

DATE: May 8, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on April 30, 1987. At this time the selected different types of hatch, airlock, and system geometry were presented. On May 1, 1987, the two probable configurations for the hatch/airlock geometry were sent to Vince Cassisi at NASA Kennedy Space Center in Florida via Federal Express. On May 3, 1987, another group meeting was held at which time specifics of the hatch hinge/locking mechanisms were evaluated. On May 5, 1987 a conference phone call was placed to Vince Cassisi and Dennis Matthews. They felt that the modular hatch design would be of more use to NASA as the hatch could be used in other parts of the moon base.

2. Tim Cory worked on conceptual drawings depicting proposed arrangement of structural stiffening members. He also assisted Capel English in the finite element analysis of the pressurized airlock skin.

3. Capel English generated the FEM mesh for the airlock and performed preliminary displacement, stress, and reaction analyses.

4. Rose Hardman coordinated with library personnel during the information search process and prepared and transmitted the letter to Vince Cassisi providing the descriptions of the alternative designs. She also investigated door linkage mechanisms for the final airlock design.

5. Joanna Martinez researched NASA reports on contaminant control systems used in previous space missions, such as the lunar module and skylab. She also obtained information on possible ventilation apparatus.

6. Kevin Moss contacted several O-ring manufacturers in the Atlanta area in order to obtain some specific recommendations for the material needed for the hatch door seal.

7. Mile Wileman worked on the evacuation system schematic and incorporated flow system performance into evacuation time calculations.

8. Mark Wolaver researched materials for the airlock skin. He investigated the material properties for aluminum, aluminum alloys, and various type of composite polymers.

SDRC I-DEAS 3.8: Pre/Post Processing
DATABASE: THIN SHELL MODEL OF PERSONNEL AIRLOCK
VIEW: VIEW1
Task: Mapped Mesh Generation

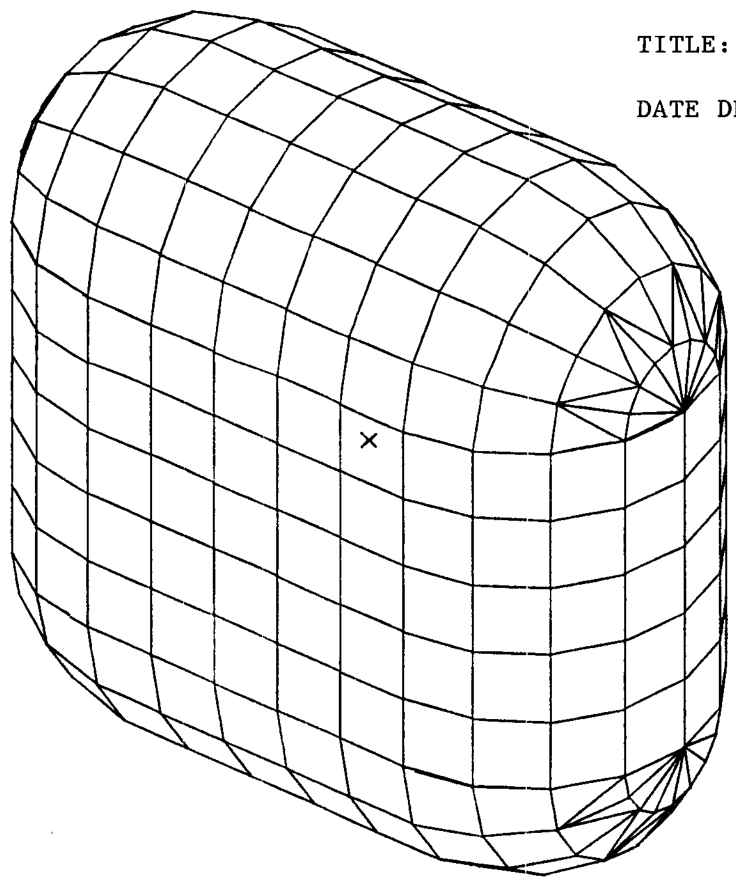
7-MAY-87 10: 48: 41
UNITS = BG
DISPLAY: No stored OPTION

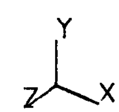
PERSONNEL TRANSFER AIRLOCK

GROUP 1

TITLE: THIN SHELL MODEL

DATE DESIGNED: 5/07/87





MEMORANDUM

DATE: May 14, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on May 8, 1987. He presented the group with information from NASA concerning space suit dimensions and the hatch/airlock design specifications associated with these requirements. On May 10, 1987, another group meeting was held. During this meeting the size of the airlock chamber was adjusted to accommodate the larger than expected space suit size. Another group meeting was held on May 12, 1987. At this meeting various mechanisms for hinging and locking the hatch door were discussed. It was decided that yet more information must be found on this subject before the final design could be chosen.

2. Tim Cory assisted in the finite element analysis of the pressurized airlock skin and the hatch door. He also continued work on possible orientations of weight saving reinforcements to increase the strength of the airlock/hatch.

3. Capel English continued the generation of the FEM mesh for the airlock and performed preliminary displacement, stress, and reaction analyses. He also began the FEM analysis for the airlock with possible reinforcing members attached.

4. Rose Hardman researched various hinge designs using the Thomas Register and the VSMF catalog. She also located potential companies to manufacture the selected hinges and completed the coordination with the library personnel for the information search.

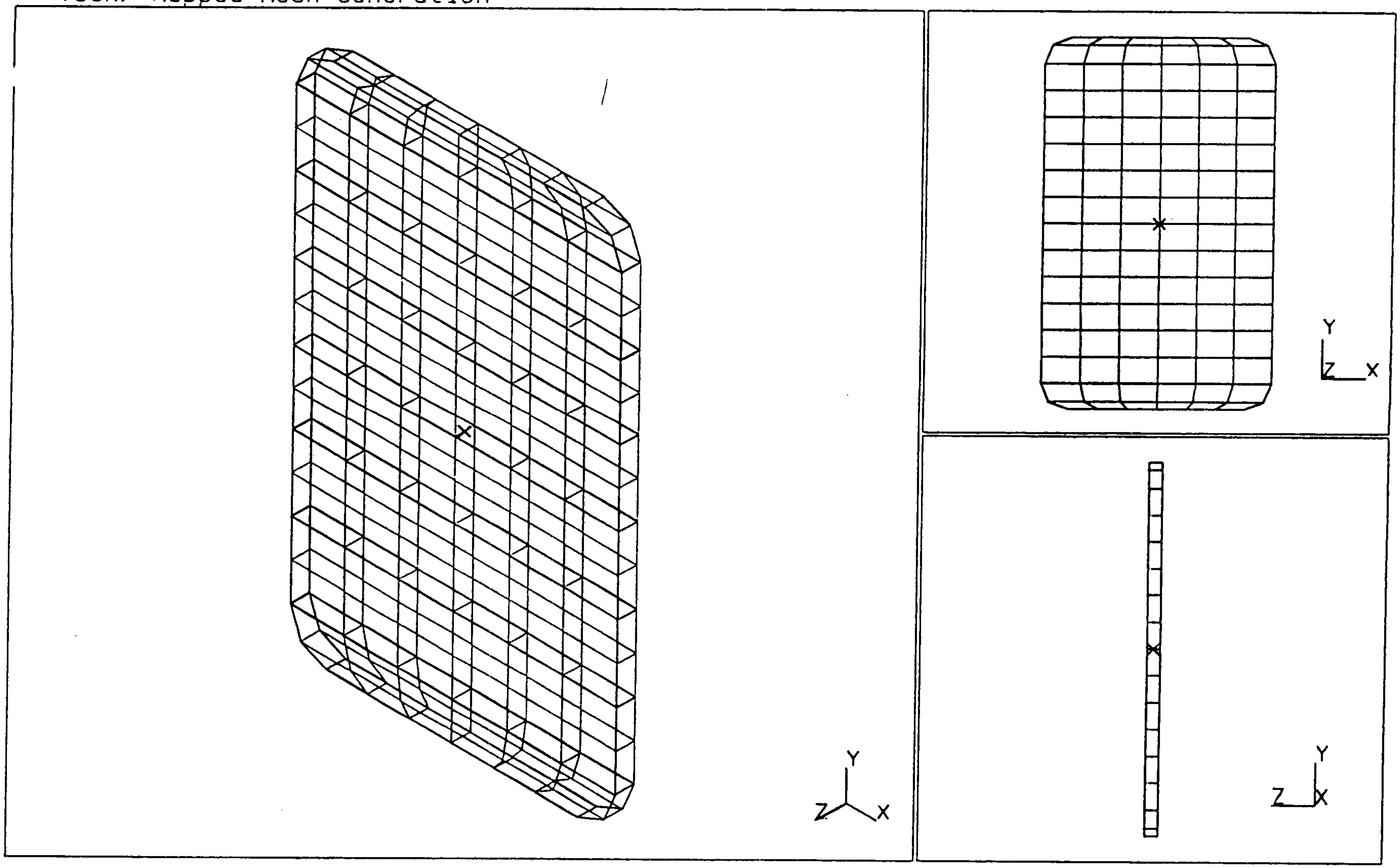
5. Joanna Martinez performed VSMF research on blowers and clean room industries and determined specifications for the blower/filtration system within the airlock.

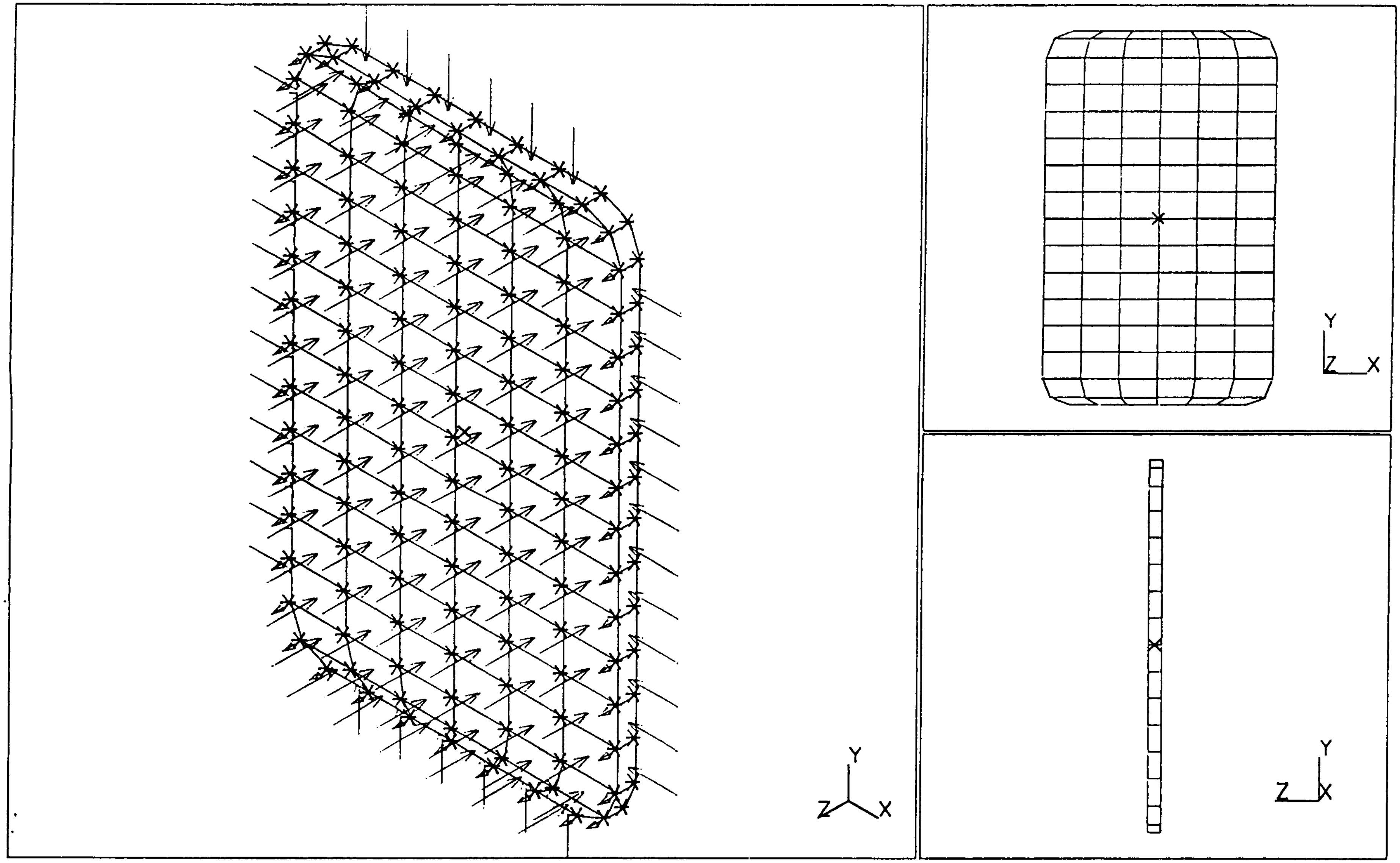
6. Kevin Moss used the VSMF catalog to locate other possible manufacturers of seals for the hatch. He also assisted in the FEM analysis as well as compiling the memorandums for the entire quarter to date.

7. Mile Wileman finalized the details of the vacuum system and completed the preliminary piping system schematic. He also performed a computer simulation using the new parameters for the system.

8. Mark Wolaver brainstormed ideas for the hatch door locking mechanisms. He also researched the Thomas Register for already manufactured latches. did airlock skin materials research. He investigated the material properties for aluminum, aluminum alloys, various type of composite polymers.

SDRC I-DEAS 3.8: Pre/Post Processing 13-MAY-87 17:41:57
DATABASE: HATCH DOOR UNITS = IN
VIEW: 2, 1, 2 DISPLAY: none, none, none
Task: Mapped Mesh Generation





Y
Z
X

MEMORANDUM

DATE: May 21, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on May 14, 1987. At this time various specific design considerations concerning the airlock were discussed. Another group meeting was held on May 17, 1987. During this meeting various systems of the airlock were divided among group members so that details of each system could be completed. Another group meeting was held on May 20, 1987. This meeting was held so that all individual work would remain coordinated with the ultimate goals of the group.

2. Tim Cory began work on a 1/10 scale model of the airlock using design specifications from the group. He also assisted Capel English in designing the structural reinforcements for the shell of the airlock.

3. Capel English continued the FEM analysis of the hatch and airlock. From his analysis it was decided that more reinforcement would be needed for the airlock shell; thus, he began work on the reinforcements and their analysis.

4. Rose Hardman organized all material to date and began preparing the rough draft of the technical report. She also assisted Tim Cory in the design of the scaled airlock model.

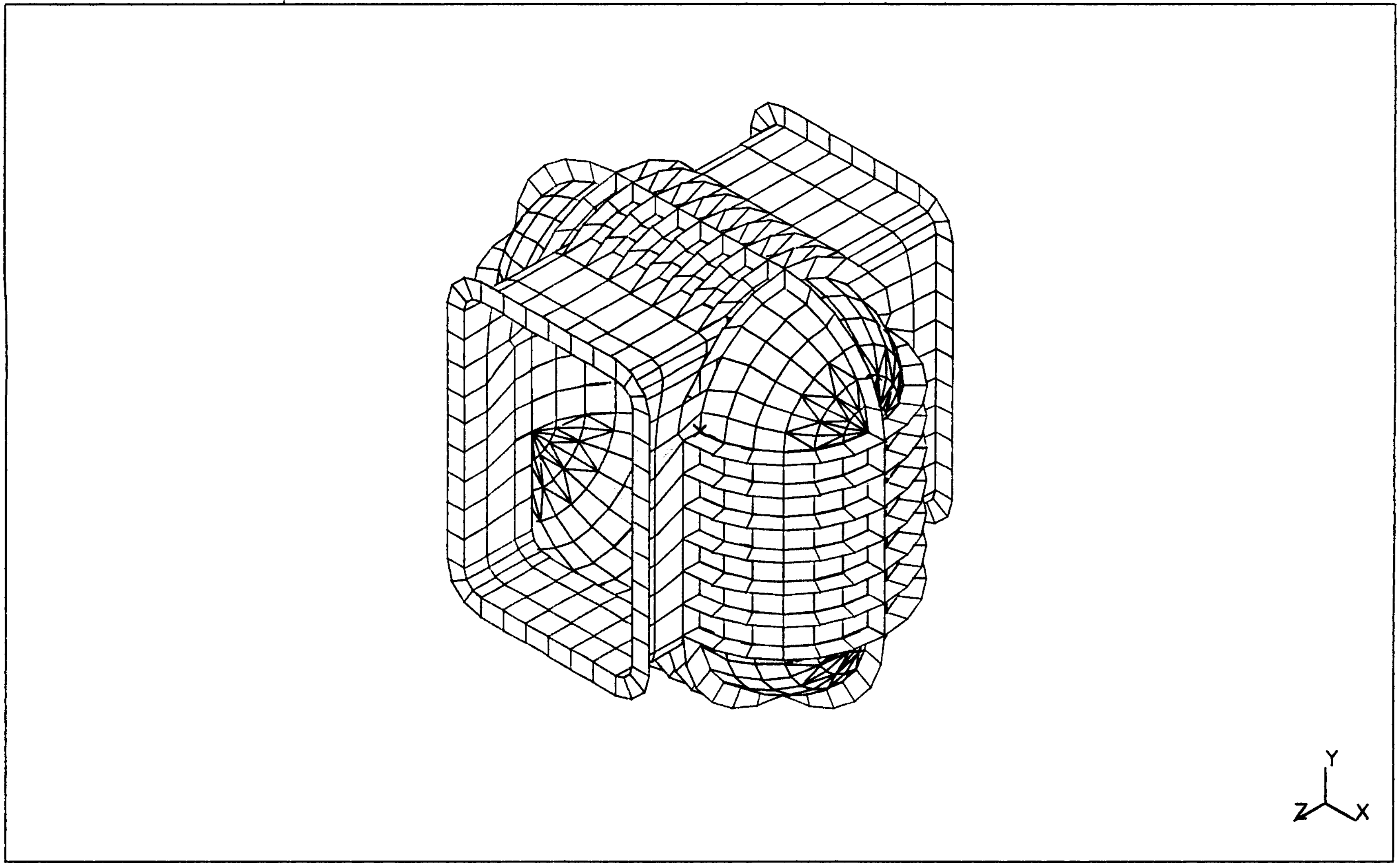
5. Joanna Martinez began detailing the particulate removal system. These details included specifications for the recirculation fan, motor, and the needed filters.

6. Kevin Moss began the details of the seal design, locking mechanisms, and hinging of the door. He also assisted in the material selection for the scaled model.

7. Mike Wileman completed the vacuum system design. He also began incorporating the seal, locking mechanism, and door hinges into one system so as to insure all components would work in unison.

8. Mark Wolaver began learning a CAD system for the preparation of the drawings to be included in the final report.

SDRC I-DEAS 3.8: Pre/Post Processing 21-MAY-87 10:40:15
DATABASE: REINFORCED AIRLOCK UNITS = IN
VIEW: No stored VIEW DISPLAY: No stored OPTION
Task: Model Preparation



MEMORANDUM

DATE: May 28, 1987

TO: Mr. Brazell

FROM: ME 4182 Group 1

SUBJECT: Weekly Progress Report - Personnel Transfer Airlock

1. A group meeting was held with Mr. Brazell on May 21, 1987, at which time part of the technical report was reviewed. The method of locking the door was also discussed and the possibility of using two light doors instead of one heavy door was mentioned. Another group meeting was held on May 24, 1987. During this meeting the decision was made to use one strong, heavy door instead of the two lighter doors. This decision was made after careful consideration of relative weight, complexity , astronaut convenience, and cost of manufacture and transportation.

2. Tim Cory continued work on the 1/10 scale model. He also helped write the portion of technical report dealing with the geometry of the airlock.

3. Capel English completed the finite element analysis of both the hatch door and the airlock module. He also helped write the portion of the technical report dealing with the hatch and door specifications.

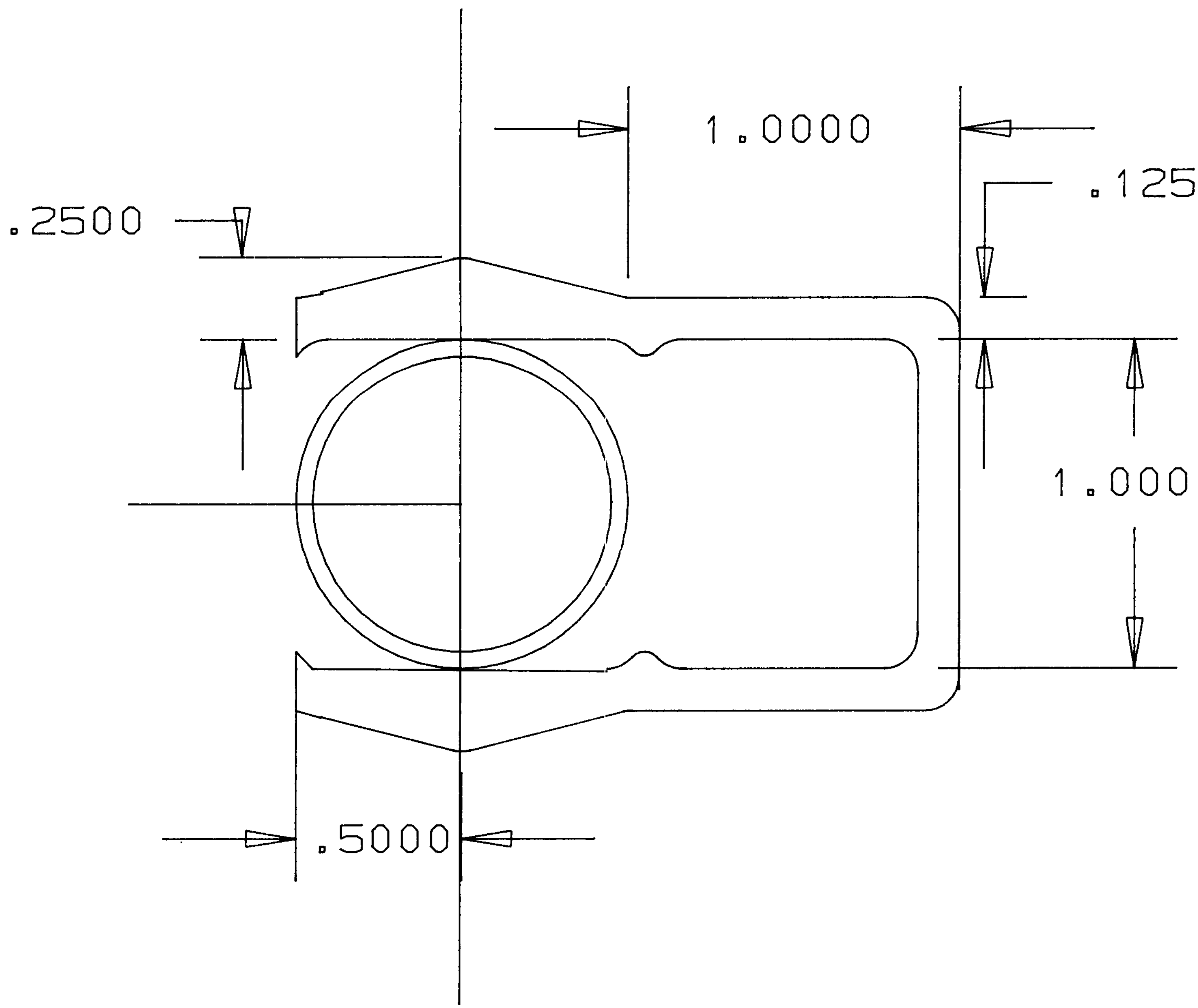
4. Rose Hardman compiled, added, edited, and typed the rough draft of the final report so that it would be available for inspection during our final group meeting with Mr. Brazell on May 28, 1987. She also acquired information from the manufacturer about the hinges we have selected in our design.

5. Joanna Martinez finished the particulate removal system for our airlock. She also helped write the portion of the technical report dealing with this cleaning system.

6. Kevin Moss helped with the analysis of the required sealing forces for both the one and two door passage systems and worked on the locking mechanism required to provide the sealing forces. He also helped write the portions of the technical report dealing with locks and

7. Mike Wileman finalized the vacuum system and helped prepare this portion of the technical report. He also helped with the finalization of the seal and the locking mechanism and helped write these portions of the technical report.

8. Mark Wolaver used the ICEM CAD system to prepare some of the necessary drawings for the technical report.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GT20 87/06/01. 04.41.41. BDBV

APPENDIX 6 PATENT APPLICATION

Disclosure No.____________

GEORGIA INSTITUTE OF TECHNOLOGY

INVENTION DISCLOSURE APPROVAL SHEET

The following questions should be answered by the laboratory or school director, as applicable. The questions are designed to verify the source of the invention and to obtain the viewpoint of other technically qualified scientists as to the uniqueness and efficiency of the invention. This approval MUST be completed before submission of the Invention Disclosure Form to the Office of Technology Transfer.

1. Title of Invention

Personnel Transfer Airlock

2. List of Inventor(s) Group 1

Kyle M. Hardman	Kevin Moss
Carol English	Micheal Wileman
Timothy Cory	Mark Wolaver
	Joanna Martinez

3. Ownership

In my opinion this invention is:

__√__ A. Owned by the University in accordance with the Patent Policy.

_____ B. Was developed by the inventor(s) without use of University time, facilities or materials and is not related to the inventor's area of technical responsibility to the University. Belongs to the inventor(s).

4. Advisor approval for student submissions (if applicable):

_______________________ Advisor

_______________________ Date

Reviewed for University Ownership by laboratory or school director.

_______________________ Name

_______________________ Date

_______________________ Title/Unit

Disclosure No.__________

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

Submit this disclosure to the Technology Transfer Office (TTO) or contact the TTO for assistance. Disclosure must contain the following items: (1) title of invention, (2) a complete statement of invention and suggested scope, (3) results demonstrating the concept is valid, (4) variations and alternate forms of the invention, (5) a statement of the novel features of the invention and how these features distinguish your invention from the state of the art as known to you, (6) applications of technology, and (7) supporting information.

1. Title

Technical Title: Personnel Transfer Airlock

Layman's Title (34 Characters): Airlock

Inventor(s): (Correspondence, patent questions, etc. will be directed to the first named inventor)

A. Signature______________________Revenue Share%____ Date__________

Printed Name In Full______________________Citizenship______
First Middle Last

Home Address______________________________

City______________County__________State__________Zip Code______

Campus Unit/Mail Address____________________Campus Phone__________

B. Signature______________________Revenue Share%____ Date__________

Printed Name In Full______________________Citizenship______
First Middle Last

Home Address______________________________

City______________County__________State__________Zip Code______

Campus Unit/Mail Address____________________Campus Phone__________

C. Signature______________________Revenue Share%____ Date__________

Printed Name In Full______________________Citizenship______
First Middle Last

Home Address______________________________

City______________County__________State__________Zip Code______

Campus Unit/Mail Address____________________Campus Phone__________

Disclosure No.___________

(Continuation Page)
DISCLOSURE OF INVENTION

2. Statement of Invention

Give a complete description of the invention. If necessary, use additional pages, drawings, diagrams, etc. Description may be by reference to a separate document (copy of a report, a preprint, grant application, or the like) attached hereto. If so, identify the document positively. The description should include the best mode that you presently contemplate for making (if the invention is an apparatus) or for carrying out (if the invention is a process) your invention.

Figures and "description" contained in the report provide a complete description of the invention.

Inventor(s)______________ Date__________ Witness____________ Date___________

______________ Date__________ Witness____________ Date___________

______________ Date__________ Witness____________ Date___________

Disclosure No.__________

(Continuation Page)
DISCLOSURE OF INVENTION

3. Results demonstrating the concept is valid

Cite specific results to date. Indicate whether you have completed preliminary search studies, laboratory model or, prototype testing.

Finite element analysis of airlock vessel and hatch has yielded results which indicate the vessel can withstand the pressure differential on the lunar surface with only minimum deflection.

A library information search was performed and information was obtained which supported the airlock design proposal.

The exhaust system was completely analyzed and optimized based on pump time and pump size. An existing pump has been recommended for the evacuation system.

4. Variations and alternative forms of the invention

State all of the alternate forms envisioned to be within the full scope of the Invention. List all potential applications and forms of the Invention, whether currently proven or not. (For example, chemical inventions should consider all derivatives, analogues, etc.) Be speculative in answering this section. Indicate what testing, if any, has been conducted on these alternate forms.

1. Attachment of standardized hatch to other vessels besides the airlock such as module to module or module to a vessel to be unloaded.

Inventor(s) GROUP 1 Date June 87 Witness__________ Date__________

__________ Date__________ Witness__________ Date__________

__________ Date__________ Witness__________ Date__________

Disclosure No.___________

(Continuation Page)
DISCLOSURE OF INVENTION

5. Novel Features

a. Specify the novel features of your invention. How does the invention differ from present technology?

There is no existing airlock designed for use in a lunar space station. The airlock is equipped with a cleaning system to clean personnel of lunar particulate. Also, the standardized hatch design of the airlock allows for the hatch to be used elsewhere in the lunar station.

b. What is the deficiency in the present technology which your invention improves upon, or the limitations it overcomes?

The airlock design withstands the pressure differential existing on the lunar surface. Also, all materials were chosen to allow for negligable offgassing effects as well as to avoid air leakage.

c. Have you or an associate searched the patent and/or scientific literature with respect to this invention? Yes ✓ No______. If Yes indicate the literature found which you believe to be pertinent to your invention and enclose copies if available.

Seal designs currently used in space technology

d. Indicate any other art, either in the literature or technology used by others, of which you are aware that is pertinent to your invention and enclose copies if available. (Note: An inventor is under duty by law to disclose such art to the U.S. Patent and Trademark Office.)

Current technology employed in the design of transfer airlocks used in submarines and in nuclear power plants.

Inventor(s) Group 1 Date Jun 87 Witness___________ Date___________

___________ Date___________ Witness___________ Date___________

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Disclosure No.____________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

6. <u>Application of the technology</u>

List all products you envision resulting from this invention, and whether these products could be developed in the near term (less than 2 years) or long term (more than 2 years).

1. Possible derivative designs of the airlock may be utilized in commercial applications, such as power plants, in the near term.
2. Larger forms of the existing airlock design may be used in future space applications
3. The air shower may be used in commercial clean room applications.

Inventor(s)	Group 1	Date	Jun 87	Witness		Date	
		Date		Witness		Date	
		Date		Witness		Date	

Disclosure No.________________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

1. As there publications-theses, reports, preprints, reprints, etc. pertaining to the invention? Please list with publication dates. Include manuscripts for publications (submitted or not), news releases, feature articles and items from internal publications.

See references, page 39 + 40 of report.

2. What was the date the invention was first conceived? May 1, 1987 Is this date documented? NO Where?________________ Are laboratory records and data available? Give reference numbers and physical location, but do not enclose. All finite element analysis and evacuation system analysis data is recorded in the GA. Tech computer system.

3. A literature search should be done by the inventor to determine publications relevant to the Invention. Please list and any related patents known to you. Numerous airlocks are utilized in industry today.

4. Date, place, and circumstances of any disclosure. If disclosed to specific individuals, give names and dates.

5. Was the work that led to the invention sponsored? If yes, check the appropriate blank(s). Government agency____, industrial company____ university ✓ other____.

Sponsor	Project No.
Georgia Institute of Technology	

6. What firms do you think may be, or are interested in the invention. Why? Name companies and specific persons if possible.

NASA : Vince Cassissi

Applications in the lunar base project.

Disclosure No.________________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

7. Being for the moment the Devil's Advocate, what do you see the <u>greatest obstacle to the adoption of your invention?</u>

The current design incurs large transportation costs due to its weight

8. <u>Alternate technology and competition</u>

a. Describe alternate technologies of which you are aware that accomplish the purpose of the invention.

Airlocks designed for different pressure differentials

b. List the companies and their products currently on the market which make use of these alternate technologies.

Nuclear power industries and submersible vehicles often use airlocks for transport of personnel. Airlocks are also used in industries where clean rooms are required

c. List any research groups currently engaged in research and development in this area.

NASA : Kennedy Space Center

9. <u>Future research plans</u>

a. What additional research is needed to complete development and testing of the invention? What are the time frames and estimated budget needed for completion of each step?

Optimization of weight of airlock
Testing of entire design

b. Is this research presently being undertaken? Yes ✓ No_____ Actively pursued? Yes ✓ No_____ If yes, under whose sponsorship? NASA
If no, should corporate sponsorship be pursued? Yes_____No_____.